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ATHABASKA OIL SANDS: APPARENT EXAMPLE OF LOCAL ORIGIN OF OIL[1]

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ABSTRACT

In the debate on local origin versus long-distance migration of oil, some consideration may well be given to the oil sands of northern Alberta, Canada. Here are many thousands of square miles of oil-saturated sands, containing up to 100,000 and more barrels of oil per acre. Estimates of the total oil content run from 100 billion to 250 billion barrels. The oil sands seem to lie too flat to have induced oil migration. There is no suggestion of artesian or metamorphic fluid movement into the area from without. The sand appears to be saturated throughout most if not all of its horizontal extent; there seems to be no large additional sand area whence the oil in the saturated area might have migrated. No deeper porous bed is known which might have brought oil into the area from remote sources. Whether the oil originated in overlying beds and migrated downward into the sand, or in underlying beds and migrated upward, or in the sand itself, the evidence suggests that the oil originated in its present location.

INTRODUCTION

In the debate on long-distance migration versus local origin of oil, some consideration may well be given to the oil sands of the Athabaska region in northern Alberta, Canada. Here are many thousands of square miles of oil-saturated sands, exposed in outcrops through a distance of 260 miles,[3] so that they have been studied, measured, and sampled, and found to contain oil up to 100,000 barrels and more per acre, under conditions strongly suggesting that the oil in each acre originated in that acre. The total oil content has

[1] Read before the Association at the Oklahoma City meeting, March 25, 1932. Manuscript received, October 26, 1934.

[2] Consulting petroleum engineer, First National Bank Building.

[3] Measured lineally along the trace of the beds, up one side of the Athabaska Valley and down the other, following the trace up each tributary valley and back.

been estimated at 100 billion to 250 billion[4] barrels; it may even approach 500 billion. The manner of accumulation of such a huge quantity of oil, if it were determined, might shed some light on the rules of accumulation elsewhere.

These oil sands have been extensively described and discussed by S. C. Ells of the Canadian Mines Branch, K. A. Clark of the Research Council of Alberta, and others. Many of the facts here given have been either taken or verified from the observations of Ells,[5] although he should not be charged with the inferences drawn from them. Unfortunately for the present purpose, many of the studies made have been devoted to the occurrence and character of the deposit and the recovery and use of the oil rather than to the geologic relationships of the deposit and the origin of the oil. Much caution is therefore necessary in drawing conclusions, and those here given are tentative, even in the mind of the writer.

GENERAL GEOLOGY

Most of northern Alberta is a vast high plain or plateau, 1,500 to 2,000 feet above sea-level, lying east of the Rocky Mountains. Beneath the prairies, swamps, and forests that cover this plain are glacial deposits, and beneath these are Cretaceous and underlying beds. Through this plain and into and even through the Cretaceous beds the major streams of the region have cut narrow, precipitous valleys, most of them scarcely more than canyons.

The stream that has cut deepest is Athabaska River, the principal headwater of the Mackenzie River system. This stream and some of its tributaries have cut through the Cretaceous into the Devonian, and have thus laid bare the remarkable oil-sand series that lies unconformably atop the Devonian limestones.

Any traveler in northern Alberta sees many interesting things, but none so likely to interest him or to stimulate his imagination as the great cliffs and slopes of bituminous sand along the banks of the Athabaska River. The exposures, some of them over 200 feet high, are found for a distance of 100 miles along the river, and for a considerable distance up its tributary streams.[6]

[4] S. M. Blair, Research Council of Alberta; personal communication to Gustav Egloff and Jacque C. Morrell quoted in paper on "The Cracking of Bitumen from Canadian Alberta Tar Sands" delivered before Amer. Inst. Chem. Eng., December 6, 1926. Also S. C. Ells, "Bituminous Sands of Northern Alberta: Operations during 1930," *Mines Branch No. 723-1* (1931), p. 6.

C. P. Bowie, "The Bowie-Gavin Process," *U. S. Bur. Mines Tech. Paper 370* (1926), p. 1.

[5] Ells has personally studied more than 300 outcrops, besides drilling a number of bore-holes and digging a number of shafts through the oil sands and making a detailed topographic map of the region in which the sands are exposed. The most complete summary of his work is *Mines Branch No. 632* (1926).

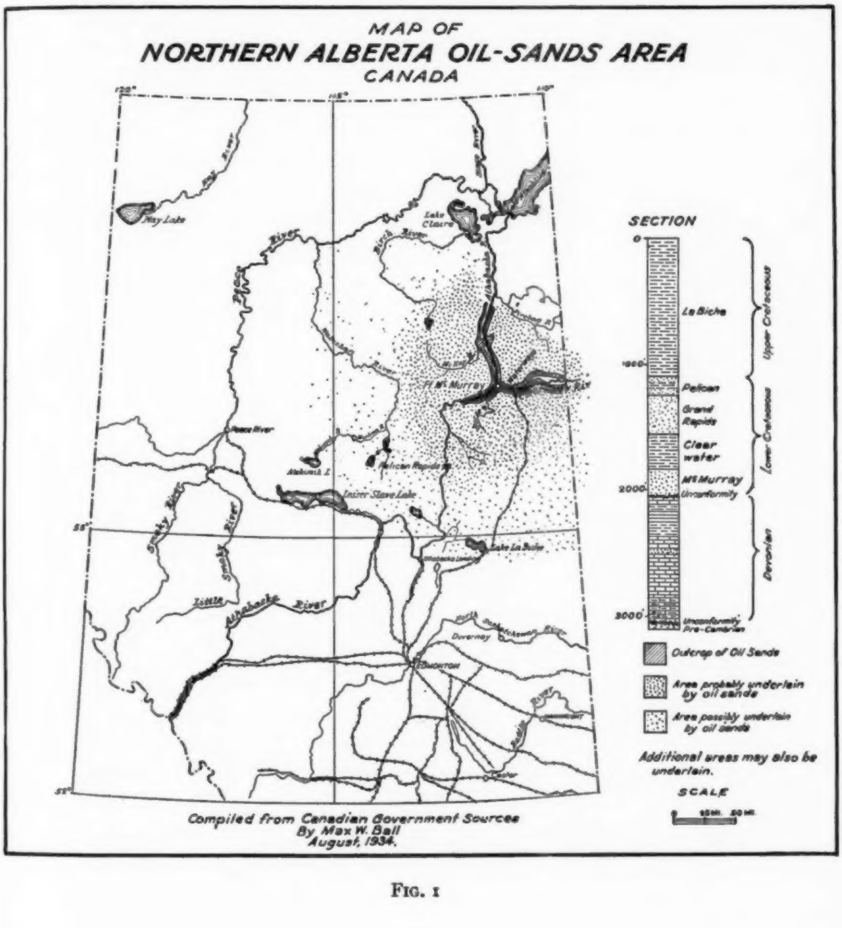
MAP OF
NORTHERN ALBERTA OIL-SANDS AREA
CANADA
Lake Claire
Birch River
Peace River
Lesser Slave Lake
Pelican Rapids
Ft McMurray
Smoky River
Little
Athabaska River
Edmonton
SECTION
Le Biche
Pelican
Grand Rapids
Clear water
McMurray
Unconformity
Unconformity
Pre-Cambrian
Upper Cretaceous
Lower Cretaceous
Devonian
Outcrop of Oil Sands
Area probably underlain by oil sands
Area possibly underlain by oil sands
Additional areas may also be underlain.
SCALE
Compiled from Canadian Government Sources
By Max W. Ball
August, 1934.

FIG. 1

The exposed rocks in the Athabaska region are shown in the following table by McLearn[7] as given by Hume.[8]

TABLE OF FORMATIONS

		Drift	*Thickness in Feet*	*Gravels, Sand, and Clay*
Cretaceous	Montana	LaBiche formation	1,100	Gray and black shales with layers of concretions at various horizons. Marine
Cretaceous	Colorado	Pelican sandstone	35	Crossbedded sandstone, conglomeratic at top. Central part continental. Top and base marine
Cretaceous	Lower Cretaceous	Pelican shale	90	Black shale. Marine
Cretaceous	Lower Cretaceous	Grand Rapids formation	280	Sandstone. Upper part continental with thin coal seams. Lower part concretionary, carrying marine fossils
Cretaceous	Lower Cretaceous	Clearwater formation	275	Soft, gray shale, black shales, gray and green sandstones with some concretionary layers. Marine
Cretaceous	Lower Cretaceous	McMurray formation	110 to 180	Sandstone, massive and crossbedded. In certain places conglomerate and more rarely clay and shale are found at the very base. Parts are highly impregnated with bitumen. Continental
		Unconformity		
Devonian			220+	Limestones

As stated in the table, the McMurray sand, which contains the oil we are considering, is of continental origin, "a delta deposit of sands containing bitumen,"[9] probably derived from the erosion of the Laurentian uplift on the east and northeast.[10] The available evidence

[6] K. A. Clark and S. M. Blair, "The Bituminous Sands of Alberta," *Scientific and Industrial Research Council of Alberta Rept. No. 18, Pt. I, Occurrence* (1927).

[7] F. H. McLearn, *Geol. Survey of Canada Sum. Rept. 1916*, p. 146.

[8] G. S. Hume, "Oil and Gas in Western Canada," (2d ed.), *Geol. Survey of Canada, No. 2128* (1933), p. 230.

[9] G. S. Hume, "Distribution of Probable Source Rocks in Relation to Natural Gas and Petroleum Production in Alberta," *Proc. World Petroleum Congress, London*, Vol. A (1933).

[10] In recent years Ells has collected from the McMurray specimens of wood, apparently preserved by the bitumen in the sand, which suggest that the formation may

indicates that the sand thins rapidly toward the south and southwest and is probably not present as a continuous sand body more than 125 miles or so southwest of its exposures along the Athabaska. The extent to the west is uncertain, but in the Peace River country, 200 miles west, no sand is present at the McMurray horizon. The overlying marine beds also appear to thin out and disappear toward the southwest from their exposures near Fort McMurray, though they probably have an extent somewhat greater than the McMurray.

The McMurray sands lie unconformably on Devonian beds. Where the writer has seen the Devonian it is a hard, compact, bluish gray limestone. Ells says the Devonian consists of

> shales, the character of which has not been definitely determined, and of highly fossiliferous limestone. Where well exposed the limestone comprises hard massive bands alternating with rubbly and highly argillaceous strata.[11]

The following summarized log of a well at Fort McMurray gives further information regarding the Devonian:[12]

Feet	
0–40	Overburden
40–415	Limestones and shales
415–782	Limestones and shales, with anhydrite, gypsum, and salt lenses, and cavities
785	Devonian-pre-Cambrian contact
789	Bottom of well

The upper surface of the Devonian is remarkably smooth and level and must represent a most advanced stage of peneplanation. Except for slight rolls a few feet high and a few hundred feet across and for possible broad structural features with dips of 1–5 feet to the mile, it lies practically flat, and on its flat upper surface the McMurray lies without appreciable angular unconformity.

AREA OF THE OIL SANDS

The McMurray or oil-sand formation, as has been said, is exposed along Athabaska River and its tributaries, chief among which is Clearwater River, the valley of which probably represents the former upper valley of the Athabaska itself.

The focal point of the exposed area is Fort McMurray, at the junction of the Athabaska and Clearwater rivers, the end of steel

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possibly be as old as Jurassic, which might make it of Morrison age. S. C. Ells, "Bituminous Sands of Northern Alberta: Operations during 1930," *Mines Branch No. 723-I* (1931), pp. 5–7.

[11] S. C. Ells, "Bituminous Sands of Northern Alberta," *Mines Branch No. 632* 1926), p. 18.

[12] *Ibid.*, p. 22.

from the south and head of navigation on the Athabaska-Mackenzie system to the north. From Fort McMurray the exposures extend 65 miles north down the Athabaska, where they terminate against recent lake deposits; 65 miles or more east up the Clearwater, where the eastern limit has not been mapped, and 40 miles southwest up the Athabaska, where they pass beneath the river bed. About 80 miles farther south up the Athabaska, near Pelican Rapids, wells have penetrated the sands and found them saturated as at the outcrop, though apparently considerably thinner. Wells near Athabaska Landing, another 80 miles southwest up the Athabaska, near Duvernay, about 140 miles southeast of Pelican Rapids, in the Wainwright field, 200 miles south of the Pelican wells, and near Castor, about 35 miles farther south than Wainwright, find a sand or sands at or near the base of the Lower Cretaceous, but this sand, which is apparently overlain by non-marine sediments and which carries water and no oil, is probably not continuous with the McMurray.[13] In the Peace River country, nearly 200 miles west of the westernmost outcrop, the sands of the McMurray are apparently not present, but wells have found heavy oil at about the same, though perhaps a higher, horizon and an oil and gas seep at about the same horizon is found on the bank of Peace River at Tar Island.[14]

A line drawn through the Pelican wells and the outermost outcrops circumscribes an area of some 10,000 square miles. If saturation extends west from the outcrop for 80 miles (the distance from the outcrop to the Pelican wells) the saturated area would be some 20,000 square miles. If saturation extends another 20 miles south of Pelican and west from the outcrop more than 80 miles, the area might be increased to 30,000 square miles or possibly more. It appears, then, that saturated sands underlie at least 10,000, probably 20,000, and possibly 30,000 or more square miles.[15]

OIL CONTENT

The McMurray formation is 100 to 200 feet and more thick. The oil content varies from nothing to 25 per cent.[16] Clark gives the following excellent description.[17]

[13] Conclusion after discussions with Frank Rohwer, who has given the problem serious study.

[14] S. C. Ells.

[15] Of the enormous total area, the area in wh`-h the sands are accessible and minable is probably less than 20 square miles, but the 20 square miles are estimated to contain about 1 billion barrels of oil.

[16] All percentages given are by weight.

[17] K. A. Clark and S. M. Blair, "The Bituminous Sands of Alberta," *Scientific and Industrial Research Council of Alberta Rept. No. 18, Pt. I, Occurrence* (1927), pp. 3-4.

The bituminous sand formation, where it can be seen, consists of a thickness of from one to two hundred feet of lenticular beds of sand and clayey material, more or less impregnated with bitumen. . . . A pronounced asphaltic smell is given off from the exposed beds. The bituminous sand in the face is dark brown to black in color. Little streaks of bitumen can be seen at some sections of the face where small quantities have come to the surface and slowly worked down. The bedding of the formation is apparent. Strata thickening or pinching out laterally can be seen, as well as irregular and cross bedding. The beds of richly impregnated sands stand out in bold cliffs, while lean beds and layers of silt and clay form gentler slopes, and are less easily distinguishable.

The bituminous sand in well impregnated beds is a very compact material. The surface can be picked into easily with a sharp pointed tool, but a heavy blow makes a surprisingly small impression. If a lump is removed it is found to be soft, in the sense that it yields to pressure and breaks down into a disintegrated mass. Close inspection shows that it is composed of an aggregation of fine sand particles, each of which is enveloped by a film of a soft, sticky bitumen. The sand is composed essentially of quartz with relatively small quantities of mica and other materials.

The degree of oil saturation has depended in part at least on the grading of the sand. The medium-grained and more massive sands are generally the richest; the finer, and particularly the more clayey and more banded, parts of the formation are in general lean.

The oil is not a pore-space filling, but is present as a film around each grain of sand. In the more massive and richer beds, at least, it is the sole cementing material. On the removal of the oil, loose, sugary sand remains.

In a few exposures the formation is uniformly saturated from top to bottom, but in most faces rich beds and lean are exposed, with the richer beds at or near the base, as a rule, and the upper beds leaner and more banded. Outcrop sampling, shafting, and core-drilling show many beds with average contents of 15 to 20 per cent, with a few as high as 25 per cent. Some of the outcrop areas carry 100,000 to 125,000 barrels per acre and some areas may run notably higher.

We do not know, of course, the average saturation, average thickness, or average content of the entire area; we do not even know its extent. A few figures, however, based on various assumptions, will give an idea of the possible quantity of oil with which we are dealing.

A bed 100 feet thick with an average saturation of 10 per cent contains 133,000 barrels per acre. In order to arrive at a reasonably conservative guess let us divide it by ten, to give an average thickness of 20 feet with 5 per cent saturation, or 40 feet with a 2½ per cent saturation. We may be above or below the truth, but we have a figure of 13,300 barrels per acre. Call it 13,000 and apply it to the minimum

probable saturated area of 10,000 square miles. The result is 80 billion barrels. Such a saturation under 20,000 square miles would give 160 billion barrels. If the saturated area should reach 30,000 square miles, the total oil content, on this basis, would be 240 billion barrels. Increase the area, the thickness, or the saturation, and you will easily double or treble these figures—and you may also exceed the truth.

Note that these are billions, not paltry millions, but remember that in all probability only a billion barrels or so are accessible to development at present-day prices.

CHARACTER OF OIL

Before we consider the method of accumulation of such a stupendous amount of oil, let us consider briefly the character of the oil.

It is an asphaltic-base material, very heavy, high in sulphur, only semi-liquid at ordinary atmospheric temperatures, with a specific gravity of 1.00 to 1.07, which, upon the A.P.I. scale, ranges from 10° to 1°, but it contains from 10 per cent to 25 per cent or more materials boiling below 300°C. and may be processed by cracking to yield from 20 to 35 per cent of gasoline. It begins to crack, in fact, at temperatures considerably below normal cracking temperatures; in order to determine its true boiling points vacuum distillation and fractionation must be employed. Distilled under atmospheric pressure, about 60 per cent is recovered as a synthetic distillate with a gravity of about 32° A.P.I., the residue being a solid asphalt or pitch. The synthetic distillate under fractionation at atmospheric pressure behaves as do ordinary oils.[18]

Such behavior suggests the possibility that this oil has not been subjected to the heat and pressure incident to folding as have the oils obtained in most fields; perhaps structural heat and pressure for long periods of time have given most well oils a gentle cracking which Athabaska oil has not had; perhaps such oils are more nearly akin to the 60 per cent synthetic distillate oil than to Athabaska oil in its natural state.

Because of its viscous nature Athabaska oil has been variously called "tar," "asphalt," and "bitumen," but the term tar is correctly applicable only to the products of destructive distillation, the term asphalt is scarcely accurate for a substance containing a considerable percentage of volatile hydrocarbons, and the term bitumen is too

[18] The statements in this paragraph are based on various laboratory tests by the Fuel Testing Laboratories, Mines Branch, Ottawa, A. J. Smith Engineering Corporation, Kansas City, Western Research Corporation, Denver, Universal Oil Products Co., Chicago, and Cross Laboratories, Kansas City.

broad to be definitive, since it is broad enough to include hydrocarbons obtainable only by distillation, such as the bitumen in bituminous coal. So far as present evidence shows, the substance is an oil, similar in origin and general character to the heavier grades of oil of Mexico and California—lighter, in fact, than the oil at Casmalia, California.

Much theorizing has been based on an assumption that this oil is the residue from the evaporation of lighter and more normal oils. Superficially the oil may resemble a residuum in appearance, viscosity, and specific gravity, but this oil under distillation or cracking does not behave as do ordinary residuums; it begins to decompose or crack at much lower temperatures. In all likelihood this is not an old oil that has lost its lighter constituents, but is rather a young oil that has never been geologically gently cracked or decomposed into lighter and heavier fractions.

Another fact militates against the assumption that the oil is an evaporation residue. At Pelican Rapids, 80 miles from the nearest outcrop and at depths of 650 to perhaps 1,000 feet, the McMurray sands contain oil of the same character as that at the outcrop. If this is residuum, how did the evaporation take place?

This evaporation-residuum assumption suggests, in passing, a few stimulating mental exercises. How much oil must have been evaporated to leave 100 to 250 billion barrels of residuum? Where did so much oil come from, and in what reservoir was it contained while the evaporation was going on?

ATTITUDE OF BEDS

As previously stated, the oil sands were laid down on an extraordinarily flat surface of Devonian limestone, and they remain practically as flat as when they were laid down. The base of the McMurray at its easternmost mapped exposure on the Clearwater is about 860 feet above sea-level. At Fort McMurray, about 20 miles northwest, it is about 800. Sixty miles down the Athabaska it is about 750. Within the exposed area are a few minor wrinkles, measurable vertically in feet and horizontally in hundreds of feet, and possibly a few broad rolls measured vertically in tens of feet and horizontally in miles,[19] but the net result is a great area in which the beds lie practically flat, with no folding except a westward dip, perhaps depositional, of 3 feet or so to the mile away from the pre-Cambrian Laurentian

[19] Some of the Canadian geologists discuss the "Athabaska anticline" and a "half-dome" in the Fort McMurray region, but their descriptions show these features to have dips of 1–5 feet to the mile.

Plateau on the east. Farther southwest, outside the exposed area, the beds dip $5\frac{1}{2}$ feet to the mile, and south of the Pelican wells they dip 10 feet to the mile[20] to Athabaska Landing. South of a line running a few miles north of Athabaska Landing and Duvernay they steepen to 20 feet or more to the mile, with the regional dip modified by local folds.[21] These steeper dips, however, are toward and beyond the margins of, rather than within, the main area of oil saturation.

A possible confirmation of the lack of such structure as to produce differences in fluid pressures lies in the fact that although more than 50 wells and core-drill holes have been drilled to the oil sands in the Athabaska area, and although many of these report water in the sands, none report flowing water.

WHENCE CAME THE OIL?

Here, then, is a great area of flat-lying sands saturated with a tremendous aggregate volume of oil. How did the oil get where it is?

Ruby has advanced the idea that the oil in certain sands in Utah is oil which formerly filled the reservoir of some closed structure or structures, has been released by erosion, has grown heavy through oxidation as it has been carried down the streams into the sea, and has been deposited on the sea floor, within the sands in which it is now found.[22] In support of the application of the theory to the Athabaska sands it might be said that the oil is almost if not quite heavy enough to be deposited with other sediments, and that the absence of cementing material in the sands and the preservation without silicification of considerable quantities of wood suggest that saturation followed soon after, if it was not contemporaneous with, deposition. Such a supposition, however, only leads from one difficulty to another. From what source could such billions of barrels of oil have come; in what manner could they have been deposited so uniformly over so wide an area? Since only a source comparable to the present deposits could have supplied such quantities of oil, why not, if we must imagine such a source area, accept the present one? The work of Beckman[23] and of Tausz,[24] moreover, indicates that oil afloat in water is attacked and destroyed

[20] Charles Camsell and Wyatt Malcolm, "The Mackenzie River Basin," *Canadian Geol. Survey Mem. 108* (1921), p. 69.

[21] F. C. Rohwer, oral communication, February 28, 1933.

[22] Glen M. Ruby, "Peculiar Phases of Oil Saturation in Certain Sandstones," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 5 (September–October, 1923), p. 473.

[23] J. W. Beckman, "Action of Bacteria on Mineral Oils," *Industrial and Engineering Chemistry*, Vol. 4, No. 21 (November 10, 1926).

[24] J. Tausz, "The Action of Micro-Organisms upon Crude Petroleum," *Petroleum Zeitschrift* (March 15, 1918), p. 553.

by aerobic bacteria, which would seem effectually to negative the possibility that this oil has been eroded from some previous source, transported by water, and deposited under water in its present location.[25]

In 1915 Huntley[26] suggested that the Athabaska oil might be the residue of large quantities of oil flushed by hydraulic movement out of the Great Plains geosyncline to the Athabaska outcrop. At that time the McMurray sand was generally considered Dakota and the Dakota was thought to be a continuous sheet sand throughout most of its Rocky Mountain and Great Plains extent. Huntley's theory was that the compacting of the Dakota sand and overlying shales and the subsequent uplift of the western and southern boundaries of the geosyncline forced great quantities of connate and meteoric water out through the Athabaska outcrop, and that this water carried with it much of the Dakota oil from the entire geosyncline, so that the oil now found in the McMurray sand is the oxidized residue of oil gathered from the Great Plains region as far south as Colorado and Kansas.

Leaving aside the evidence that the Athabaska oil is not a residuum, Huntley's theory seems to be negatived by other evidence developed since his paper was presented. Further study of the Dakota has shown that it is far from being a continuous sheet sand. In the words of Lee:[27]

> There is no single, definite, persistent, and easily recognized sandstone such as was formerly supposed to exist and was termed the Dakota sandstone. In its place there is a group of intimately related beds. . . . Doubtless there are many overlapping lenses that differ slightly in age.

Moreover, the McMurray sand is not now considered a member of the Dakota group. It apparently disappears toward the west and south, at least as a continuous sand body, and is apparently not continuous with any sand that underlies the greater part of the geosyncline. In the absence of a continuous sheet sand or sandy zone, the theory loses its attractiveness.

Is it not possible, however, that the oil may have been moved into the Athabaska area by "metamorphic circulation"? Parks[28]

[25] The articles by Tausz and Beckman were called to the writer's attention by Alex. W. McCoy.

[26] L. G. Huntley, "Oil, Gas, and Water Content of Dakota Sand in Canada and United States," *Trans. Amer. Inst. Min. and Met. Eng.* (1915), pp. 329–52.

[27] Willis T. Lee, "Continuity of Some Oil-Bearing Sands of Colorado and Wyoming," *U. S. Geol. Survey Bull. 751*, pp. 7–22.

[28] E. M. Parks, "Migration of Oil and Water, a Further Discussion," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 8, No. 6 (November–December, 1924), pp. 697–715.

points out, most persuasively, that metamorphic circulation, due to compacting of sediments and reduction in pore space by whatever cause, is of greater importance than artesian circulation in the accumulation of oil, and that it is as likely to take place across as with the bedding. In the Athabaska country, however, the Devonian sediments were compacted long before the McMurray sands were laid down; no metamorphic circulation took place from them into the present oil sands. After the McMurray sands and overlying shales were laid down there was, no doubt, a lively fluid movement due to compacting, but this movement probably took place before erosion had exposed the McMurray sands, and there is no reason, therefore, to think that extensive fluid movements from outside the area into the McMurray sands took place. Because the beds lie so flat the metamorphic circulation was probably chiefly vertical, with local lateral movements to points of vertical escape. Metamorphic circulation, then, seems to provide no outside source for the oil.

Some geologists have thought the oil originated in beds of Mississippian age in southern Alberta, where the Lower Cretaceous lies unconformably on the Mississippian Madison or Turner Valley limestone which contains the principal producing zones of the southern Alberta and northern Montana oil fields, and that it floated northward in a Lower Cretaceous sea and saturated the depositing McMurray sand. This theory is akin to Ruby's, if not identical with it, and it is subject to the same objection: aerobic bacteria would doubtless have destroyed any such oil before it reached the point of deposition.

As to the alternative suggestion that oil originating in the Mississippian migrated northward into the McMurray sand along the Paleozoic-Lower Cretaceous unconformity, the Mississippian, like the Devonian, was compacted long before the deposition of the McMurray, so that there would be no metamorphic circulation from the Mississippian into the Lower Cretaceous, and there is no reason to think that artesian circulation along the unconformity has been such as to move such quantities of oil such a distance.

If we must rule out Ruby's theory that the oil was deposited with the sand, Huntley's theory that the oil has been funnelled into the Athabaska region through a continuous Dakota sand, and the suggestions of others that the oil has been brought in by metamorphic or artesian circulation through the McMurray sand or along the Paleozoic-Lower Cretaceous unconformity, how about the possibility of migration from some remote region through deeper-lying "carrier beds"? Dismissing all questions regarding the geographic and geologic location of a source for so much oil, and all questions regarding the

relation of such migration to the long period of exposure of the Devonian surface before the deposition of the McMurray, we still encounter two formidable difficulties: (1) the pre-McMurray beds contain, so far as we know, no continuous sandstones or other continuous zones of porosity to act as "carriers"; (2) the Devonian beds were doubtless compacted and indurated to their present degree of impermeability long before the McMurray beds were laid down, and though fractures are known to extend short distances downward into the Devonian, the region seems to be devoid of deep-seated faulting or of other vertical lines of porosity that would permit migration upward from Devonian or older "carrier beds" into the McMurray. Courses along which the oil could have moved into the area and along which it could have moved upward into the sands seem both to be lacking, so that we are forced, however reluctantly, to set aside this theory also.

The more we study the facts, and the more we try to imagine some other answer, the more we seem to be forced to conclude that the source of the oil was co-extensive with its present location. The oil is apparently a young oil, not yet subjected to the vicissitudes of heat and pressure, rather than the residuum of larger volumes moved in from some outside source. The beds are too flat, it would seem, to have induced migration. There is practically complete absence of water pressure, or of any indication of artesian movement. There is nothing to suggest that during compaction of the sediments fluids moved into this area from without. The McMurray sand appears to be saturated throughout most or all of its extent; there seems to be no additional larger area of the sand whence the oil in the saturated area could have been derived. No deeper-lying porous beds which might have brought oil into the area from remote sources, or vertical channels into the oil sands from such deeper-lying porous beds if they existed, are known. The evidence may be mainly negative, but point by point it indicates that the oil originated in its present location.

Whether or not it originated in the McMurray sandstone is another question and not particularly important in the present discussion. It may have originated in the shales above, which are similar in character to shales ordinarily considered the source of much Rocky Mountain oil—a theory supported by the fact that the saturation and the shales immediately overlying the sand seem to be co-extensive. It may have originated in the underlying Devonian; the fact that several wells drilled into the Devonian report gas or oil showings may be significant, but if so, why did the oil not migrate upward during the long interval when the Devonian was exposed to erosion?

It may have originated in the sands themselves, though the amount of organic material that must have been required for its production would seem to demand too great a volume for such a sandstone to contain. It may even have had an inorganic origin in the pre-Cambrian rocks—an idea with which one of our distinguished members seems to be flirting in Mid-Continent fields—though it is hard to see how, if so, it passed upward through the Cambrian and Devonian sediments in a region devoid, so far as we know, of deep-seated fracturing.

The point is that whether the oil originated in overlying beds and migrated downward, or originated in underlying beds and migrated upward, or originated in the sands themselves and stayed there—however it may have moved up or down, it probably has not moved far sidewise.

Whatever may have happened in other areas, in the Athabaska country the theory of local origin in its most extreme form seems to be sustained.

DISCUSSION

G. S. Hume, Ottawa, Canada (written discussion received, December 17, 1934):[29] The theory of the local origin of the oil in the Athabaska "oil sands" as given in the paper by Mr. Ball is based almost entirely on the elimination of other possible distant sources of origin. Some direct conclusions based on a discussion of the possibility of local origin would have been welcomed. This would have involved a critical examination of the stratigraphic sequence showing the relationships of the various formations and giving at least a brief account of the origin and character of all possible source beds in the McMurray area. The reference (Footnote 10) to a possible Jurassic age of the McMurray formation is unfortunate in view of the fact that other evidence of age is omitted. The suggestion of a possible Jurassic age was based only on specimens of wood without fossil leaves. The Lower Cretaceous age which is considered by the Geological Survey to be definitely established is based on the presence of one non-marine fauna[30] near the base and another depauperate marine fauna[31] near the top of the formation.

The table of formations as given by Mr. Ball shows within the Lower Cretaceous of the McMurray area an alternation of marine and non-marine strata. As all Lower Cretaceous strata in the Plains of southwestern Alberta are non-marine it is obvious that the shore lines of the former Lower Cretaceous seas must have existed south and west of McMurray. The significance of these shore lines with their probable connection with the origin of the oil that now is found in the McMurray deltaic deposit has already been out-

[29] Published by permission of the director, Bureau of Economic Geology, Department of Mines, Canada.

[30] For description, see L. S. Russell, *Trans. Royal Soc. Canada*, Vol. XXVI, Sec. IV (1932), pp. 37-44.

[31] For description and correlation, see F. H. McLearn, *Trans. Royal Soc. Canada*, Vol. XXVI, Sec. IV (1932), p. 159.

lined by the writer[32] and seems much stronger evidence of a possible near source than the hypothetical cases for long distance migration proposed and rejected by Mr. Ball. The conclusion based on a study of the stratigraphy is, in a general way, the same as that of Mr. Ball, namely, a probable near source, although the writer would not agree that there are "conditions suggesting that the oil in each acre originated in that acre."

In reference to the difficult problem of the extent of the so-called "oil sands," Mr. Ball states that "oil-saturated sands" are "exposed on outcrops through a distance of 260 miles." The writer got an entirely wrong conception of the situation on reading this statement and believes it should be qualified. The 260 miles includes[33] 118 miles of exposure on Athabaska River plus all the measured distances on tributary and in general somewhat parallel streams on the two sides of the river. The Athabaska River section is by far the most significant as far as size of deposit is concerned. From Boiler Rapids in a northeast direction for 42 miles to McMurray and from McMurray north for 76 miles exposures of bituminous sand occur. An examination of Ells' maps[34] shows that on the east side of Athabaska River the maximum width of exposures is 5 miles and on the west side the known width is 6 miles. Beyond these limits the extent of the deposit becomes somewhat problematical because the McMurray formation is a continental deposit with large-scale foreset beds and other striking characters of a delta deposit and hence may change rapidly laterally. By a fortuitous circumstance Athabaska River appears to have cut across the main part of the delta of the McMurray formation and hence any suppositional extension of the deposit laterally beyond known limits becomes somewhat hazardous. Exception might be taken therefore to the very extensive area postulated by Mr. Ball as underlain by the bituminous sands, since according to Ells[35] "it is definitely known that the area underlain by bituminous sand is not less than 1,500 square miles and the total areal extent of the deposit is probably very much greater." This is in contrast with the minimum estimate of 10,000 square miles as given by Mr. Ball. The areal extent, however, has not very much significance as far as the origin is concerned, because admittedly the amount of petroleum present even on the most conservative estimates is exceedingly large, as is shown by Ells' statement,

> field investigations by the Mines Branch indicate that at least 750 million tons of bituminous sand can be mined by open-cut methods. On a basis of 12 per cent bitumen content this is equivalent to 90 million tons of bitumen or 500 million barrels.

The character of the oil in the McMurray sands as indicated by Mr. Ball seems to the writer to be of considerable importance. A number of years ago a few wells were drilled in the Peace River area, 225 miles west of McMurray and a small quantity of oil was obtained from the base of the Lower Cretaceous. An analysis of this oil made under the direction of Stansfield and Nich-

[32] G. S. Hume, "Distribution of Probable Source Rocks in Relation to Natural Gas and Petroleum Production in Alberta," *Proc. World Petrol. Congress, 1933*, Sectional Vol. A (1934).

[33] See S. C. Ells, *Mines Branch Rept. 632, Dept. Mines, Canada* (1926), p. 29.

[34] S. C. Ells, maps to accompany *Mines Branch Rept. 632, Dept. Mines, Canada* (1926).

[35] S. C. Ells, "Some Economic Aspects of the Bituminous Sands of Northern Alberta," *Dept. Mines, Mines Branch Rept. 735* (1934), p. 11.

olls, of the Mines Branch, showed[36] that the oil "cracks at abnormally low temperatures. This phenomenon begins at 200 degrees and is particularly active between 250 and 300 degrees." McLearn, commenting on this, states that

> the presence of the heavy constituents stable at low temperatures can only be explained by the minimum temperatures to which they have been subjected, made possible in turn by the minimum stress which the enclosing rocks have undergone.

This deduction based on the character of the Peace River oil is in accord with Mr. Ball's deduction based on an apparently similar character for the McMurray oil.

In conclusion the writer desires to state that Mr. Ball has done a very great service in bringing the attention of petroleum geologists to the problems of origin connected with so large a quantity of oil as that which is found in the McMurray formation. It is hoped that the comments made in this discussion will tend to stimulate further interest.

Oliver B. Hopkins, Toronto, Canada (written discussion received, December 17, 1934): Mr. Ball in his paper appears to have outlined very clearly the extent, general character, and geological setting of the Athabaska oil sands. The evidence he presents regarding the local origin of the oil content of these sands appears to be strong, if not conclusive.

The interesting features of this oil occurrence are its wide distribution and remarkably uniform character regardless of whether the associated beds are exposed at the surface or under a cover of hundreds, if not thousands of feet.

In the Wainwright field, 200 miles south of the Athabaska deposits, sands of essentially the same age (Lower Cretaceous) buried under 1,500–2,000 feet of sediments contain oil which is considered to have the same characteristics as those of the Athabaska deposits. The Wainwright oil, under these conditions, can hardly be looked upon as a residual material. This situation and the fact that the Athabaska oil does not change materially from its outcrop to where it is buried under hundreds of feet of cover lead naturally to the conclusion that some explanation other than the loss of its volatile constituents must be responsible for its character.

Mr. Ball has submitted evidence in support of the conclusion that this oil has not been subjected to the heat and pressure incident to folding that oil in most commercially productive fields has been subjected to. The character of this oil may be due to the type of material from which it was formed, to the conditions surrounding its formation, to alterations since its formation, or a combination of these factors. If we eliminate inspissation, as the evidence indicates that we should, the most logical cause of alteration in the character of the oil would be oxidation. It is not unlikely that oxidation has played some part in determining the character of the oil, but how important it is impossible to say. The occurrence of the oil in a non-marine series of sands above an unconformity would presumably have made oxidation a possible factor of importance.

In this connection it is interesting to note that in the Plains area in sand lenses associated with marine Colorado shales, as at Kehoe Lake, an oil of considerably higher gravity (approximately 32° A.P.I.) than that commonly

[36] F. H. McLearn, *Geol. Survey Canada Sum. Rept.* (1918), Pt. C, p. 6.

occurring in the Lower Cretaceous has been found. Since this higher oil is younger and presumably has been less altered in character through heat and pressure than the oil in the underlying formations, it is concluded that probably the type of material from which this lower oil was formed was a governing factor in determining its character.

THEODORE A. LINK, Calgary, Alberta (written discussion received, December 19, 1934): Practically all geologists who come in contact with the "tar sands" of Athabaska River live through similar reactions and emotions. The nature and areal extent of the deposit impress one to such an extent that the possibility of developing them immediately takes hold. It seems ridiculous that such a vast deposit is not being worked, and the problem of extracting the oil from the sands certainly should be a simple matter. After finding out that considerable work has already been done along those lines, and then discovering that it really is not simple or economical under present conditions, the last form of interest remaining for the geologist is the problem of their origin and the source and extent of migration of the oil. Mr. Ball's contribution on the "Tar-Sand Problem" is a brief but excellent statement on the subject. In it are presented the salient features, and the conclusions are essentially the same as those of most investigators who have worked in that area. The important question with respect to the source rocks remains unanswered, and as long as such is the case, the problem considered by Mr. Ball, namely, the extent of migration, also remains undetermined.

The following data, based on my own field and laboratory investigations together with those of other workers, are submitted herewith.

The St. Peter sandstone of northern Illinois is the nearest approach to the sands obtained from the "tar sands" after extraction of the oil. The latter differ from the St. Peter sandstone merely in smaller size of grain. Both are more than 99 per cent pure white, unconsolidated quartz sandstone, and as a possible source rock for petroleum are out of the question. It is significant to note that there are barren patches or lenses within the tar sands containing no oil at all.

While experimenting with the tar sands some 15 years ago I was informed by someone at the University of Alberta, working on the same subject, that microscopic observation revealed the presence of films of water surrounding the sand grains, which films, in turn, are surrounded by the oil. This seems to be an important item to consider, and appears to be verified by the fact that low-temperature dry heat applied to fresh tar sands does not result in a clean separation of the oil from the sand. If, however, the tar sand is placed in water, and then heated to the boiling point, a complete separation of the oil from the sand is effected, leaving pure white quartz sand. In the relatively low-temperature dry heating method the sand always remains black, due to a thin coating of oil residue. This seems to be the explanation for the lack of results obtained by drilling holes into the tar sands and placing electric heaters at the bottom with the hope of obtaining free oil. The heat causes the evaporation of the thin film of water, which acts as a lubricant, and thus causes the phenomenon of "case-hardening" to develop in the sands directly surrounding the heated portion of the hole. All outcrops of the tar sands along the river banks display this phenomenon of case-hardening due to oxidation and the heat of the summer sun. The fresh exposures are easily cut into, but weathered

outcrops are more like asphalt pavements. This is an important item with respect to the mining of the tar sands.

The presence of this film of water surrounding the sand grains seems to indicate that the sands were water-logged *before* the advent of the oil, and should be considered when dealing with this problem.

I can not disprove Mr. Rohwer's assertion that the oil sands near Castor, Wainwright, and other places are not continuous with the McMurray sands, but am inclined to believe that they really are. Their physical appearance leads me to believe that these sands are the fingering out of the tar sands because of their physical composition (fine-grained white, loose quartz sands). If the source rock for the tar sands is the shale body surrounding the sides of the huge McMurray tar-sand lens, their migration toward the center is a matter of many miles and does not fit the facts to the conclusion of "the local origin of oil." Absence of high dips does not, in my opinion, preclude the possibility of migration.

Max W. Ball (written discussion received, January 10, 1935): I want to thank Dr. Hopkins, Dr. Hume, and Dr. Link for their searching and helpful criticisms and comments. If I argue some of their points it is not because my mind is closed on the subject or because I do not value their ideas and suggestions, but rather because I should like to see still further discussion.

As to the area of the sand deposit, the accompanying map (Fig. 1) tells its own story. The saturated sands are not confined to a narrow belt along a north-south river; the east-west distance from the westernmost to the easternmost known exposure is between 75 and 100 miles. The north-south distance from the northernmost known exposure to the southernmost well encountering unquestioned McMurray sand is about 115 miles. A line circumscribing these points encloses appreciably more than 10,000 square miles. This is, to my mind, the minimum probable area. As to the maximum possible area, each student of the map may make his own guess. As Dr. Hume points out, the matter is not of great importance, for the outcrop areas alone contain plenty of oil to float an argument, and the areas minable by open-pit methods contain 500 million barrels or more.

Dr. Link's suggestion of a water film around the sand grain inside the oil film is new to me, but a wire to Dr. K. A. Clark of the Research Council of Alberta, who has done much excellent work on the oil sands, brings the information that he believes such a film exists.[37] It must be pretty thin, for the moisture content of a representative sample of sand containing 18.5 per cent oil was only 1.3 per cent.[38] Regardless of the presence or absence of such a film of water, the easy separation of the oil from the sand by hot water is probably due to a lowering of the surface tension of the oil film without cracking of the oil. The surface tension is further decreased, and separation at lower temperatures is obtained, by making the water slightly alkaline. In our pilot plant at Toronto we are using 0.1 per cent sodium silicate in water at 160°–190°F. The hardening of the oil sand under dry heat is doubtless due to the cracking of the oil and the consequent development of hard pitch or coke. As already

[37] Personal telegram, January 3, 1935.

[38] S. C. Ells, "Bituminous Sands of Northern Alberta," *Mines Branch Rept. 632* (1926), p. 50.

stated, the oil is extremely sensitive to heat and "cracks if you look at it," a point much in its favor from the refiner's viewpoint.

This unusual sensitiveness to heat has become even more apparent during further studies of the oil, made with laboratory-scale vacuum, atmospheric, and high-pressure units since the manuscript of my paper was submitted.[39] Digestion in a closed system at 684°F. more than doubles the A.P.I. gravity of the oil, and multiplies many-fold its percentage of low-boiling fractions. The following table is illustrative.

	Percentage of Gasoline (400 End Point)
Athabaska crude oil	0.5
After digestion in closed system at 684°F.	7.0
After cracking at 800°F. at 1,000 pounds	22.5

This work has given added evidence of the virgin character of the oil. Mahoney says,[40] "This oil bears a relation to ordinary oil similar to that borne by lignite to bituminous coal. A bit of heat and pressure will convert one into the other." It no longer seems necessary to consider such factors as possible oxidation or possible variations in source material to account for the nature and behavior of Athabaska crude. Either or both may have had a share, but the important factor seems to have been the absence of the amount of heat and pressure to which all ordinary oil is subjected.[41] The result is an oil that has the gravity and viscosity of a residuum but none of the other characteristics; that instead of being refractory is surprisingly sensitive; that looks like a residuum but is not.

Now if this is a virgin and not a residual oil, its viscosity is doubtless as low now as it ever was. If so, how could it have migrated into its present position from any distance, no matter how short? At 100°F. a good strong pump would be required to force it through a 2-inch pipe. How much pressure would have been required to induce it to migrate through the pore spaces of a fine-grained sand? Such a movement seems improbable, to say the least. Once more we are forced to think that, horizontally speaking, the oil originated about where it now is.

In closing let me protest that this is not, as Dr. Link seems to imply, my "last form of interest" in the Athabaska sands, following a discovery that extracting the oil from the sands is "not so simple or economical." If Dr. Link can find an opportunity to visit our pilot plant in Toronto he will see the oil being extracted from the sand by a method both simple and economical, and being refined by a diversity of modern methods. Perhaps, if all goes well, we can show him a commercial unit in operation at Fort McMurray before another winter. On full-scale operation we hope to produce oil at a cost that will be considered a low price for crude in any man's country. At any rate this paper, wangled out amidst the multitudinous details of an active development project, is by no means my "last form of interest" in the Athabaska oil sands.

[39] The work is being done in Toronto by the A. J. Smith Engineering Corporation of Kansas City, for Canadian Northern Oil-Sand Products, Ltd., by A. J. Smith, president, and George F. Mahoney, vice-president.

[40] George F. Mahoney, informal communication.

[41] It is most interesting to learn from Dr. Hume that McLearn of the Canadian Geological Survey reached this conclusion about 17 years ago with reference to oil of the same age from the Peace River country.

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MARINE OIL SHALE, SOURCE OF OIL IN PLAYA DEL REY FIELD, CALIFORNIA[1]

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ABSTRACT

A black nodular marine oil shale, 100–150 feet thick, lies directly upon the basal Miocene producing conglomerate of the Playa del Rey field and 1,500 feet below the upper producing zone in the overlying Pliocene. Since the basal M. cene producing conglomerate rests directly upon Franciscan (Jurassic?) schist, evidence for downward migration into this conglomerate is good.

The nodular oil shale contains an abundance of free oil and pyrobituminous material and is by far the most highly organic shale body in the field. Geological and chemical evidence, based on several lines of attack, are presented to support the contention that this oil shale is the most likely source for the Playa del Rey crude.

INTRODUCTION

The data presented in this paper result to a large extent from a study of cores that reveal an almost complete record of the sedimentary rocks underlying the Playa del Rey oil field. The title indicates that the authors have unquestionable proof as to the source of the oil in this field. It appears that the establishment of proof of this sort is impossible for any problem concerning the source or origin of oil. The oil whose source is being studied can not be observed during its formative process; this natural process is complete, or if not, is almost certainly too slow to be detected in operation. The marine organic material from which the oil has been derived has lost its original characteristics and in all oil-producing areas may well be entirely unidentifiable. It is true that much identifiable organic matter is present in rocks suspected of being the source of oil, but in some instances at least there is reason to believe that this organic material is still recognizable because it has withstood those chemical changes which are necessary for oil formation, and that the oil has been derived from less stable types of organic matter which may have been present in

[1] Read before the Pacific Section of the Association at Los Angeles, November 7, 1930, and before the Association at the San Antonio meeting March 20, 1931. Manuscript received, August 7, 1934. Published with the permission of Desaix B. Myers, chief geologist, and R. E. Haylett, director of manufacturing, of the Union Oil Company of California.

[2] Geologist, Union Oil Company of California.

[3] Chemist, research department, Union Oil Company of California.

great abundance but, as evidence of its presence, has left behind only a multitude of thin brown laminations and minute brown specks detectable in thin sections, and possibly a heavy bituminous residue and odor. It does not seem unreasonable, therefore, to suspect that the most highly organic rocks of an area, particularly black carbonaceous shales, have an organic content far different from that of the original sea-bottom ooze from which these rocks were formed. The common failure of experimenters to develop appreciable amounts of free oil by subjecting oil shale to pressure and low temperature should not be considered as evidence that even more moderate pressure and temperature have not been sufficient to produce oil from the original organic sediment during the metamorphosis of this sediment to oil shale.

Better opportunity for success in pressure and low temperature experiments to form oil would appear to exist when these experiments are applied to recent marine organic oozes similar to those that have been responsible for our highly organic shales and limestones.

Even though it appears impossible to establish unquestionable proof as to the source of oil, it is possible in some areas, by a process of elimination based upon the belief that commercial deposits of oil have been derived from organic matter, to conclude safely that only a few stratigraphic horizons exist that offer reasonable possibilities. Investigation of these stratigraphic horizons may result in the accumulation of evidence decidedly in favor of one horizon. Study of the chemical and petrographic character of the rocks at this horizon and of their contained bitumens, together with the character of the crude oil being produced, may develop corroborative evidence that will warrant a tentative conclusion that this horizon has been a source of oil, and probably the only important source of the crude oil being produced. It should be remembered, however, that other horizons originally considered as possibilities were eliminated probably because of negative or incomplete evidence and the inability of the investigator to find cause for believing them worthy of further consideration as important possibilities. These discarded possibilities may deserve more thought than the present evidence indicates, but until their importance is strengthened by exact information they must be considered as less likely possibilities.

An attempt is made in this paper to evaluate all possible sources for the oil being produced in this field. A preponderance of evidence in favor of one possibility has encouraged the writers to draw rather definite conclusions.

Acknowledgments

W. H. Bradley, of the United States Geological Survey, has made microscopic examinations of thin sections of the nodular oil shale and has granted permission for the publication of his descriptions as a part of this paper. Parker D. Trask, also of the United States Geological Survey, has read this paper and has made several valuable and constructive criticisms. S. G. Wissler, paleontologist of the Union Oil Company, has supplied information which has aided in classifying the stratigraphic section of the Playa del Rey field. Paul L. Henderson, chief geologist of the Ohio Oil Company in California, has made available suites of cores from several wells within this field.

Geology

The Playa del Rey oil field occupies a flat coastal area of tidal swamps and sand dunes 15 miles west of Los Angeles (Fig. 1). Recent deposits cover the surface and conceal all evidence of favorable oil-field structure within the producing area. Lying just north of the field is a prominent crescent-shaped area of late Pleistocene rocks whose topographic form suggests that it may be the surface expression of the northwestern end of the Playa del Rey anticline. Except for this suggestion, which is not very strong, there appears to be no evidence that this structure has undergone post-Pleistocene folding.

STRUCTURE

Lack of information prevents description of the geologic structure of the entire area which ultimately will prove productive at Playa del Rey; it is apparent, however, that an anticline of major proportions is present, and that this anticline is broken locally by faults (Fig. 2). Future development may reveal that faults are more widespread and have had a greater influence upon the structural development of the area than is indicated by present available evidence. The anticline now appears to strike about N. 50° W. The fold is broad and gently flexed, with average dips of 0°–20° except in those local areas where faulting has produced minor drag folds and steeper dips. The total closure is unknown, but may exceed 1,500 feet; closure of the lower oil zone within the ultimate producing area is probably 900–1,000 feet.

The northwestern trend of the Playa del Rey line of folding must terminate within a short distance to the northwest, where it presumably abuts against a major east-west zone of faulting that borders the southern edge of the Santa Monica Mountains, northwest of Santa Monica.

FIG. 1.—Topographic map of the Playa del Rey area, by the United States Geological Survey. Contour interval, 5 feet. Present producing area (March, 1931) shown by stippling. Probable extent of production shown by heavy broken line. Structure contours (interval, 50 feet) shown in northern part of field. Scale: 1 inch = approximately 2,960 feet.

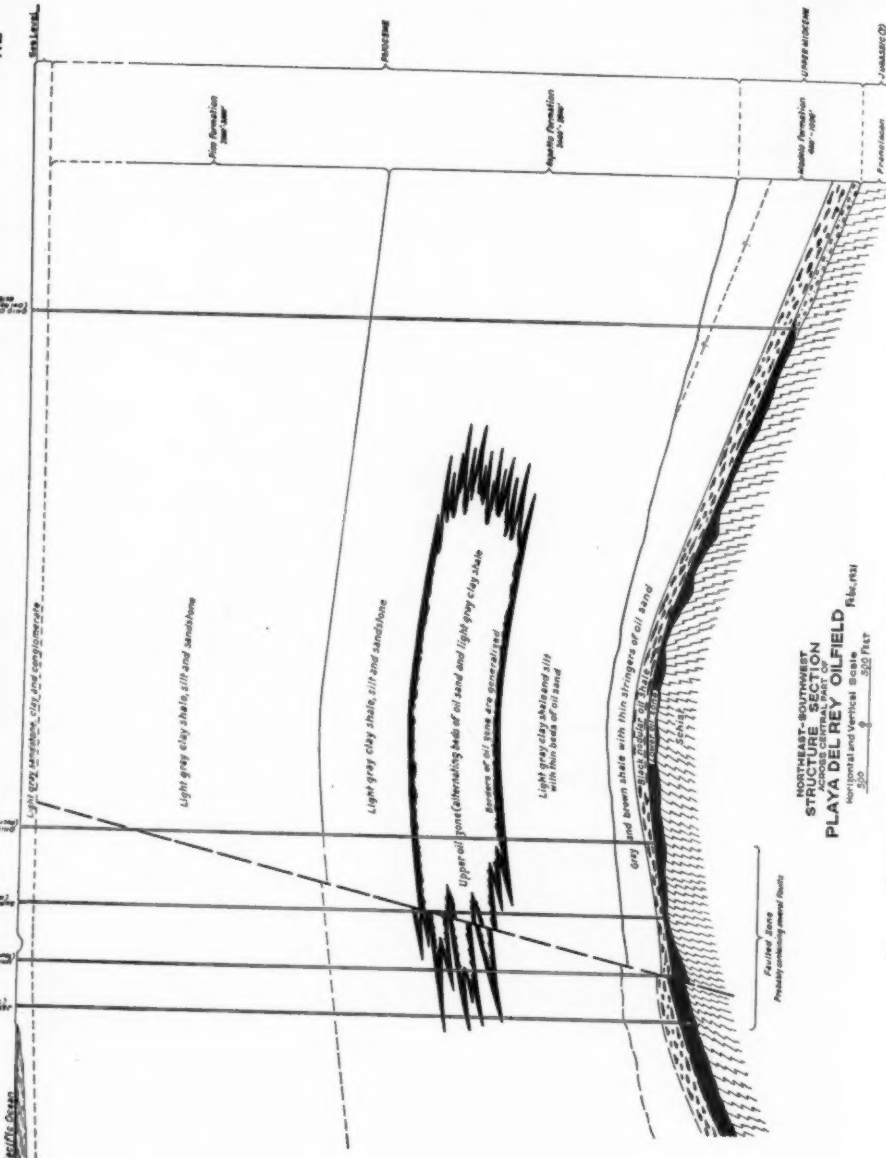

FIG. 2.—Generalized structure section across central part of Playa del Ray field.

STRATIGRAPHY

The accompanying stratigraphic table (Table I) is a composite for the entire field. The major stratigraphic units listed in this table are apparently almost uniform in character throughout the area, although minor variations are known to occur; the thickness of each of them, except possibly the Pleistocene, varies noticeably and generally attains a minimum on the crest and a maximum on the flanks of the anticline.

Possible Sources of the Crude Oil

POST-MIOCENE AND PRE-MIOCENE ROCKS

Since much of the oil and gas at Playa del Rey is found directly on top of, and along fractures in, Franciscan schist (Jurassic?), it must be considered that the oil and gas may have originated in any part of the stratigraphic section from the surface down to and including the schist.

Most of the Pleistocene and Pliocene sediments are so coarse in texture and the Franciscan schist is so highly metamorphosed that serious consideration of them as likely source material is discouraged. Of these two possibilities the Pliocene deposits are the most promising, particularly in view of the possibility that these rocks at Playa del Rey may grade laterally into finer sediments that are more highly organic. In opposition to this possible condition, however, there appears to be no evidence from cores of hundreds of wells drilled throughout the extensive Los Angeles Basin that more likely source material occurs in the Pliocene.

Because the Lower Pliocene Repetto formation contains one of the two oil zones at Venice, some of the silty clay shale in this formation, most promising, as a source, has been tested for free oil and pyrobituminous content and the results appear in Table IV. In these sediments free oil, if present, occurs in quantities too small to measure by the laboratory methods used, and the amount of solid organic material that will yield oil upon heating is small when compared with the underlying Miocene shale, particularly the nodular oil-shale horizon. The Lower Pliocene shale, when heated, yields an average of about 1 gallon of oil to the ton, whereas composite samples of the nodular oil shale yield from 8.4 gallons to 15.0 gallons to the ton and individual horizons are considerably richer. Parker D. Trask[4] considers that the yield of 1 gallon to the ton from the lower Pliocene sediments is significant in that it indicates an organic content of 3–4

[4] Correspondence, Oct. 19, 1931.

FIG. 2.—Generalized structure section across central part of Playa del Ray field.

TABLE I

STRATIGRAPHIC TABLE OF THE PLAYA DEL REY OIL FIELD

Age	Group or Formation	Description	Oil Zones	Organic Contents	Thickness
Pleistocene	? Arnold's upper and lower San Pedro and Deadman Island "Pliocene"?	Loose gray sand with some clay and fine conglomerate		Megascopic shells of marine molluscs abundant near top. *Foraminifera* fairly abundant at some horizons	? 100– 500
—?—?— Major unconformity*					
Pliocene	Pico	Soft light gray clay shale, and micaceous siltstone and sandstone. Dark carbonaceous or bituminous appearance is entirely absent		Only *Foraminifera* are abundant	2,000–3,000
	Repetto†	Soft light gray silty clay shale and micaceous siltstone and sandstone with important oil zone occupying middle 1,000 feet. Sands below main oil zone are less abundant, but all are saturated with oil in area near crest of anticline. Fractures in clay shale within the oil zone contain oil, but otherwise clay shale is devoid of carbonaceous or bituminous appearance	UPPER OIL ZONE near middle; thin oil sands occur throughout lower part	*Foraminifera* are abundant at some horizons. Otherwise clay shale appears to be comparatively lean in organic material	2,400–2,800
	Unconformity‡				
Upper Miocene	Lower member of Modelo§ Upper unit	Hard gray and brown siliceous shale, beautifully laminated in greater part. Intercalated thin beds of sand are saturated with oil in area near crest of anticline. Brown laminae appear bituminous	Thin beds of oil sand locally	Fish scales common, pelecypods rare, and *Foraminifera* of arenaceous and calcareous types common. Brown laminae yield some oil when heated	300– 700
	Middle unit	Hard black and dark brown shale containing abundant tan and light gray phosphate nodules and laminae. Well bedded, with bedding planes and fracture planes commonly containing heavy black oil. Has highly bituminous appearance	OIL SHALE	High phosphate content results from abundance of organic life. Scales and bones of fish fairly common, *Foraminifera* rare. Abundance of finely disseminated organic material, now largely unidentifiable, produces black color. Contains heavy black oil and much pyrobituminous material	75– 200
	Lower unit‖	Coarse conglomerate and sand with abundant detrital fragments of schist up to several feet in diameter; calcareous and irregularly mineralized with pyrite	LOWER OIL ZONE	Unidentifiable shell fragments appear to be rare	0– 120
	Major unconformity				
Jurassic (?)¶	Franciscan	Schist, highly metamorphosed	Oil in fractures near top	None recognizable	?

* Evidence of this unconformity in the Playa del Rey field is not positive due to scarcity of cores. At the mouth of Potrero Canyon, 3 miles northwest of Playa del Rey, gently dipping lower Pleistocene or upper Pliocene conglomerate rests directly upon almost vertical upper Pliocene rocks with angular discordance of about 60°.

† A name proposed by the Correlation Committee of the Pacific Section of the Society of Economic Paleontologists and Mineralogists and described in *International Geological Congress Guidebook No. 15* (1933), p. 31, for lower Pliocene strata exposed in the Repetto Hills, Los Angeles County.

‡ This unconformity is supported by a striking difference between the structure of the upper oil zone (Pliocene) and the lower oil zone (Miocene), and by the apparent absence in this field of 3,500–4,000 feet of upper Modelo strata which crop out on the north flank of the Santa Monica Mountains, 12 miles north of Playa del Rey. H. L. Driver, Standard Oil Company of California, states that faunal evidence does not indicate to him the presence of an unconformity.

§ The Modelo formation of the Santa Monica Mountains has been subdivided into an upper and a lower member. Only the lower part of the lower member appears to be present at Playa del Rey.

‖ Age uncertain. May be Middle Miocene or older. An unconformity may occur at its top.

¶ Generally considered Jurassic but may include older rocks of even Paleozoic and pre-Cambrian age.

per cent, and in that way compares favorably with some of the better Recent sediments that he has studied. The senior author is of the opinion that the best of the examined Recent sediments are not comparable in organic content with the best of the geologically older rocks that occur in the stratigraphic sections of oil fields. It may well be that none of the Recent sediments will ever be a source of petroeum and that they must be much richer in organic material before they will yield, under natural conditions, commercial quantities of oil. Certainly the Pliocene rocks of Playa del Rey do not constitute the most promising source of oil for this field, although it appears impossible to prove that they have not contributed some oil.

MIOCENE ROCKS

THE UPPER UNIT OF THE MODELO FORMATION OF THE PLAYA DEL REY AREA

This stratigraphic unit is considered to be the equivalent of a part of the lower member of the Modelo formation as mapped in the Santa Monica Mountains. In the Playa del Rey area its thickness varies from 300 feet on the crest of the anticline to about 700 feet on the flanks. It consists in greater part of brown and light gray hard platy siliceous shale and siltstone interstratified with thin beds of sandstone; locally the lower 50–100 feet is black and, although it contains a comparatively small amount of free oil, appears to be as highly organic as the underlying nodular oil shale. The upper few feet of this unit is usually called by drillers and scouts the "poker chip shale." Some of this shale is beautifully laminated, and the brown portions contain scattered *Foraminifera* and appear to contain a considerable amount of other organic material which is unidentifiable in hand specimens. Some of this unidentifiable organic material yields a small amount of oil when heated in a test tube. Distillation tests have been made on some of the most organic appearing portions of this stratigraphic unit and the results appear in Table IV. These results reveal that some portions of this shale contain organic material capable of producing oil, but, except for the lower 75–100 feet, the amount of oil produced is far less than that obtained by similar treatment of the underlying nodular oil shale which comprises the middle unit of the Modelo formation of the Playa del Rey area. It is concluded from the organic content of some of the thin beds and from the results of solvent and distillation tests on selected portions, that parts of this upper unit, particularly the lower 75–100 feet, may have been the source of some oil.

THE MIDDLE UNIT OF THE MODELO FORMATION OF THE PLAYA DEL REY AREA

This unit is composed of 100–150 feet of black nodular oil shale and directly overlies the lower producing oil zone of the Playa del Rey field. This brief description of the nodular oil shale is supplemented in a later part of this paper by a more detailed account of those characteristics having a direct bearing upon the present problem. In general, this stratigraphic unit is uniform in character throughout. In hardness and lamination it is similar to the overlying Miocene, but usually it is readily distinguished from this upper unit by its black color, bituminous appearance, and nodular and spotted character (Fig. 3). The black color and bituminous appearance result from

FIG. 3.—Cores cut in half. Light gray Pliocene clay-shale (on left), black nodular oil shale (in middle), and gray platy Miocene shale (on right) from upper unit of Modelo. Largest cores are 3½ inches in diameter. Cores were sawed and then broken and part of sawed surface coated with shellac. Photograph by K. E. Lohman.

an abundance of kerogen that readily yields oil when heated and from the presence of considerable heavy black oil that may be removed with ordinary solvents. The nodular and spotted nature of the shale is due to the erratic occurrence of tan and gray nodules from ¼ inch to 3 or 4 inches in diameter, some of which have a porous and occasionally an indistinct oölitic structure. These nodules are highly phosphatic and are associated with thin, discontinuous tan-colored beds and laminae of the same composition.

As is shown in the accompanying photographs (Fig. 4), the contact of this nodular oil shale with the underlying oil-producing conglomerate is irregular, very sharp, and is marked by a concentration of phosphate nodules. These features, together with apparently abrupt irregularities in the elevation of this contact throughout the Playa del Rey field, suggest that an unconformity exists at this horizon.

Evidence is presented later to support the belief that this nodular oil shale has been the source of much, if not all, of the Playa del Rey oil. This evidence results from a consideration of the following factors: (1) the character of the Playa del Rey oil and the close relation which exists between the known distribution in the Los Angeles Basin of this unusual type of oil and the known and suspected distribution of the nodular oil shale; (2) the stratigraphic relation between the nodular oil shale and producing oil zones; (3) the presence of free oil in this shale having a radically different character from that of the crude oil being produced; (4) the high kerogen content and

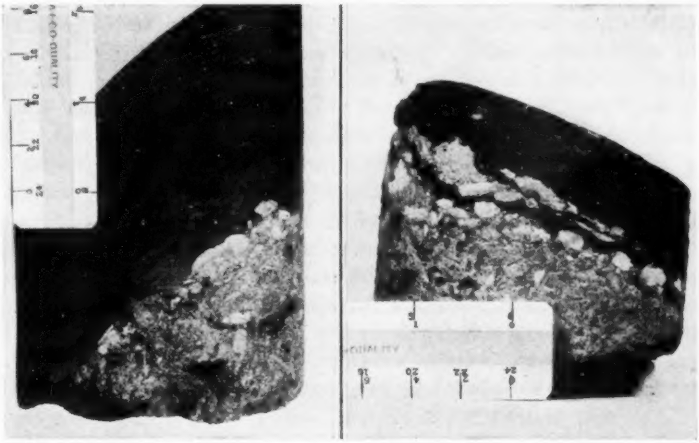

FIG. 4.—Photographs of contact of black nodular oil shale with underlying conglomerate of lower oil zone. Irregular light-colored areas along contact are phosphatic nodules. Photographs by K. E. Lohman.

the increase of the free oil-kerogen ratio downward in the supposed direction of migration; (5) the microscopic character and significance of the organic and phosphatic material; and (6) the high carbon-hydrogen ratio of this oil shale, indicating that oil formation has occurred.

THE LOWER UNIT OF THE MODELO FORMATION OF THE PLAYA DEL REY AREA

This stratigraphic unit is the basal conglomerate of the Miocene and the lower producing oil horizon of the Playa del Rey field. This conglomerate was deposited upon an uneven erosion surface of the old schist (Jurassic?) and as a result its thickness varies from 0 to 120 feet. In some areas the entire unit is conglomerate and varies in tex-

ture from fine to very coarse conglomerate with boulders up to several feet in thickness. The accompanying photograph (Fig. 4) illustrates probably the average texture of this horizon. Conglomerate of the type shown in this photograph is associated in some wells with considerable coarse sand. The color is usually dark gray or mottled greenish gray due to included pebbles, cobbles, and boulders of green and gray schist. Some of the cobbles and boulders are very well rounded, but it is common to find boulders up to 6 inches in diameter that are sub-angular with only the corners slightly rounded. The porosity of this horizon apparently ranges from 10 to 20 per cent with a probable average of about 12 per cent. Locally the original porosity has been materially reduced by impregnated iron sulphite minerals deposited by waters presumably from the underlying schist. Calcite is almost always present as interstitial material and apparently has been derived in large part from the solution of the shells of marine molluscs, fragments of which occur scattered throughout this horizon.

Since this unit is one of the two important oil-producing horizons of the Playa del Rey area, the possibility that the oil results from the decomposition of the remains of abundant marine life within this conglomerate must be considered. Coarse detrital beds are not commonly considered as probable sources of oil, but there are observations on record which indicate that oil may be derived from organic matter in such coarse material.[5] In the Playa del Rey conglomerate recognizable organic remains are scarce and it seems unlikely that animal life was sufficiently abundant at this time to be seriously considered as a possible source of much oil. There is no evidence that marine plant material accumulated on the sea floor while this conglomerate was being deposited. Even though invertebrate shallow-water animals and plants may have been abundant in the near-shore environment which received and reworked this coarse material, it seems unlikely from its coarse texture, and therefore the assumed strong surf and current action, that the animal and plant matter would have escaped oxidation and been preserved for those slowly acting chemical and bacterial processes believed to be necessary for the generation of petroleum. Except for arguments such as these, there is little evidence bearing upon the importance of this conglomerate as a source horizon for the oil at Playa del Rey. Until the evidence obtainable more strongly supports the possibility that this stratigraphic unit has been an important factor in the generation of petro-

[5] R. Potonie, *Petrographie der Ölschiefer und ihrer Verwandten* (Berlin, 1928), pp. 133–39. Discusses "bituminous sands," "sapropel sands," etc., with many references. Some of his authorities consider the oil secondary, but others, such as Hummel, consider it primary. Potonie subscribes to the latter view (p. 135).

leum, it is assumed that the oil within it has been derived from some other horizon.

The Nodular Oil Shale—The Probable Source of Oil

Of the Miocene strata within the field, the nodular oil shale is the one horizon with outstanding organic and bituminous characteristics that warrant its serious consideration as a possible important source of oil. This shale body also is in direct contact with one of the producing oil zones, a stratigraphic relation that would have permitted a comparatively simple process of oil migration.

These conditions have led to special studies of the nodular oil shale. Phases of this investigation and the evidence derived from it are discussed below under separate headings.

RELATION OF THE NODULAR OIL SHALE TO PRODUCING ZONES

The structure section shown in Figure 2 illustrates the relation of the nodular oil shale to the two producing zones of the Playa del Rey field. It will be observed that the nodular oil shale suspected of being a source rock rests directly upon the lower oil zone (see also Figure 4) and lies 1,000–1,200 feet below the base of the upper oil zone. Coring operations have shown that in the structurally high part of the Playa del Rey anticline all highly porous horizons between the two main oil zones carry oil.

No explanation appears necessary to account for migration of oil from the nodular shale downward into the contiguous lower producing zone. Since, however, the major part of the upper zone lies some 1,500 feet above the suspected source horizon, and since this interval consists largely of compact shale, clay shale and siltstone, migration from the source horizon upward into the upper producing zone is not so easily explained. Since all porous horizons between the nodular oil shale and the upper producing zone in the high part of the structure contain oil, there appears to be no good evidence against oil in the upper zone having migrated from the nodular oil shale. From our present knowledge of the impermeability of shale to oil, it appears that without the assistance of some helpful structural features as avenues for migration, oil originating in the nodular shale might encounter considerable resistance to its upward migration. Even though the pressure in the vicinity of the source bed may have been sufficient to overcome this resistance to upward migration under any structural condition, it seems probable that migration would have been greatly facilitated by the presence of zones of faulting and fracture. The structure section in Figure 2 illustrates the presence of faults on the

west flank of the Playa del Rey anticline and it is probable that other faults or fault zones occur. Fault planes and fault gouge have been cored in several instances and have been found to be associated with considerable free oil. Existing evidence warrants the belief that faults may have facilitated migration of oil upward into the upper producing zone.

CHARACTER OF PLAYA DEL REY CRUDE

The accompanying table of partial analyses presents pertinent data as to the character of crude oils from the upper and lower zones at Playa del Rey and from some of the other producing fields of the Los Angeles Basin. It will be noted that the crude oils from the two producing zones at Playa del Rey and from the near-by Torrance and Inglewood fields are similar in gravity and are characterized by relatively high sulphur content. In these respects they are similar to crude oil from the Beverly Hills field, but in this way are markedly different from the crudes of most other important fields of the Los Angeles Basin. Figure 5 illustrates the fact that all of the fields producing oils of low gravities and high sulphur contents are grouped in the western and northwestern parts of the Los Angeles Basin;[6] in view of this grouping and the similarity of the crudes, it appears reasonable to consider that these crudes, so different from other oils of the Basin, may have been derived from similar sources and may have experienced similar geologic conditions since being formed. This group of crudes may even have had a common origin in the same stratigraphic horizon, particularly if it can be shown that they, in contrast to the other oils of the Los Angeles Basin, are associated with apparently favorable source material of the same age and having the same characteristics.

It may be noted from Table II that the hydrocarbon analyses[7] of the gasolines from the high sulphur crudes reveal that these crudes are by no means identical in character. The aromatic content of the gasolines from the crude from the lower zone at Playa del Rey and from Torrance are similar but are somewhat different from that obtained from the Playa del Rey upper zone crude. Whether such differences are indicative of a separate source for the latter or have resulted from differences in environment and migration history for the Playa del Rey upper zone oil is unknown.

[6] This statement applies to crude oils having a sulphur content approaching 2 per cent. Some fields along the northern and northeastern border of the Los Angeles Basin yield oils having notable amounts of sulphur. Oil from the Central Los Angeles City field contains 1.3 per cent *S*; that from Whittier 0.93 per cent; and that from Brea-Olinda about 1 per cent (*U. S. Geol. Survey Bull. 309*, pp. 211–212).

[7] The method and limitation of the hydrocarbon analyses are described on page 293.

TABLE II
ANALYSES OF CRUDES AND GASOLINES FROM THE CRUDES FROM PLAYA DEL REY AND SURROUNDING FIELDS

Field	*Structure*	*Results of Tests on Crude*			*Distill. Range (°F.)*	*Aromatics (% by Wgt.)*	*Unsaturates (% by Wgt.)*	*Naphthenes (% by Wgt.)*	*Paraffines (% by Wgt.)*
		Gr. °API	*Sulphur (% by Wgt.)*	*Water (% by Wgt.)*					
Playa del Rey Lower Zone	High	24.2	—	0.1	114–440	13.9	6.1	50.4	29.6
	Low	22.7	2.6	Trace	150–440	15.6	2.0	54.8	27.6
Playa del Rey Upper Zone	High	22.8	2.7	0.3	106–432	7.5	2.2	51.5	38.8
	Low	22.0	2.6	0.1	105–434	6.6	2.2	53.8	37.4
West Torrance		20.5	1.9	0.2	200–440	16.2	2.0	59.2	22.6
East Torrance		23.3	1.4	0.6	196–435	16.9	2.0	53.9	27.2
Dominguez		31.3	0.8	Trace	136–431	13.4	0.7	50.7	35.2
Rosecrans		33.7	0.5	1.6	157–438	14.1	None	48.5	37.4
Potrero		38.7	0.8	Trace	162–430	16.4	None	33.9	49.7
Inglewood		18.6	2.3	0.7	171–440	11.0	0.7	73.4	14.9

FEATURES COMMON TO PLAYA DEL REY CRUDE AND THE NODULAR OIL SHALE

It has been shown that the crude oils from Playa del Rey and nearby fields have relatively high sulphur content and as a group differ in this respect from most other crudes of the Los Angeles Basin. Since the nodular shale is suspected of being the source of the Playa del Rey crude, it is of interest to make comparison between the sulphur content of the nodular oil shale and of other shale bodies within this field. In the accompanying table are shown the percentages of sulphur in the nodular oil shale, the overlying Miocene shale, and in random samples throughout most of the Repetto formation (Lower Pliocene). It is evident from this table that the sulphur content gradually increases downward in the stratigraphic column from 1.1 per cent near the upper oil zone in the Repetto formation, to 2.8 per cent for the entire nodular oil shale, and that the nodular oil shale contains a markedly greater percentage of sulphur than any other shale body in the lower part of the stratigraphic section at Playa del Rey. It would appear from this evidence that the most probable source for the Playa del Rey high sulphur crude is the nodular oil shale.[8]

TABLE III

Composite Sample Number	*Geologic Subdivision*	*Distance Above (+) or Below (−) Top of Miocene (Feet)*	*Total Sulphur Content of Composite Samples*	*Well*
1	*Pliocene*	1,730–1,740+	1.1	Ohio-Brown No. 1
2	Repetto formation	1,403–1,414+	1.4	Ohio-Brown No. 1
3		892– 900+	0.9	Ohio-Brown No. 1
4		100– 150+	1.3	Barnsdall-Burke No. 13-A
5	*Miocene*	0– 350−	1.7	Barnsdall-Burke No. 13-A
6	Modelo formation			
	Upper unit	350– 390−	1.8	Ohio-Recreation No. 4
7	Middle unit (nodular sh.)			
	top	464−	2.3	Barnsdall-Burke No. 13-A
8	Entire nod. sh.	464– 646−		

AREAL DISTRIBUTION OF HIGH SULPHUR OILS AND THE NODULAR OIL SHALE

The accompanying map (Fig. 5) of the western part of the Los Angeles Basin permits comparison of the areal distribution of those

[8] Trask considers the sulphur in these sediments to be of probable organic origin. He calls attention to the fact (correspondence dated October 19, 1931) that the *ratio* of sulphur to organic matter is much higher in the Pliocene than in the Miocene rocks and that any oil originating in the Pliocene should be high in sulphur. The relatively low percentage of organic matter and of sulphur, taken separately, in the Pliocene argues against these rocks as being the most probable source of Playa del Rey crude.

fields producing oil of low specific gravity and unusually high sulphur content with known occurrences of the nodular oil shale. This shale, in addition to being present at Playa del Rey, is exposed at two localities in the Santa Monica Mountains (see map) and is known to underlie producing oil zones in the Torrance field 10 miles southeast

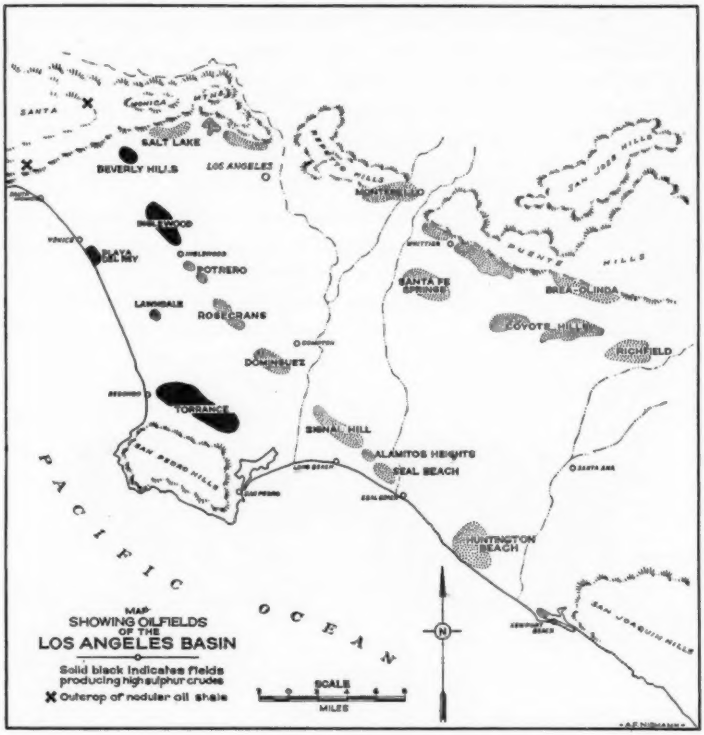

FIG. 5.—Map of Los Angeles Basin showing fields in solid black that yield unusually high sulphur crudes.

of Playa del Rey. It may be seen, therefore, that the nodular oil shale has quite an extensive distribution in the western part of the Los Angeles Basin, where it has been cored in two of the four fields producing high sulphur oils. From this distribution, it seems probable that it also occurs in the stratigraphic sections of the Inglewood and Beverly Hills fields, the two other near-by fields producing high sulphur oils. In the Inglewood field Miocene rocks have not yet been

completely penetrated, so that no opportunity is yet available to obtain proof of the presence of this suspected source rock. All development in the Beverly Hills field occurred a number of years prior to any interest in the source of this oil and no record is now available to prove or disprove the presence of the nodular oil shale in the stratigraphic section of this field.

By way of summary it may be said that oils of unusually high sulphur content are restricted, with slight exception, to the western part of the Los Angeles Basin and that the known distribution of the nodular shale is such as to warrant the conclusion that this shale body occurs within or near the fields that yield high sulphur oils.

CHARACTER OF THE NODULAR SHALE

The nodular shale as the suspected source rock for the Playa del Rey oil has been briefly described. It is a hard black shale with a highly carbonaceous or bituminous appearance and in general resembles hard black rubber except that the black color is interrupted with tan-colored laminations and irregularly shaped nodules (Fig. 6).

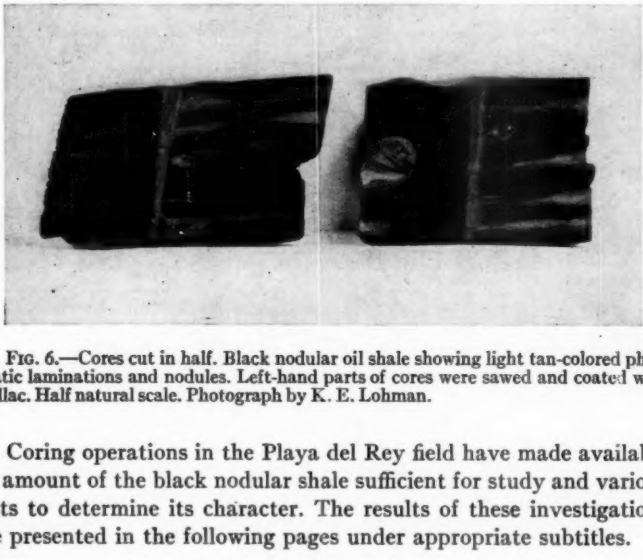

FIG. 6.—Cores cut in half. Black nodular oil shale showing light tan-colored phosphatic laminations and nodules. Left-hand parts of cores were sawed and coated with shellac. Half natural scale. Photograph by K. E. Lohman.

Coring operations in the Playa del Rey field have made available an amount of the black nodular shale sufficient for study and various tests to determine its character. The results of these investigations are presented in the following pages under appropriate subtitles.

ORGANIC MATERIAL

The black color of this rock and the presence of a large amount of free oil soluble in chloroform or petroleum ether, as well as pyro-

bituminous material which yields oil upon heating are the most outstanding megascopic evidences of the presence of organic material in appreciable quantities. The tan-colored nodules and laminations contain a high percentage of phosphorus and suggest the existence of abundant animal and plant life during the time this shale accumulated as mud. Analyses have shown that both the nodules and laminations are largely calcium phosphate; they contain as high as 12–15 per cent phosphorus, which when calculated to calcium phosphate $Ca_3(PO_4)_2$ amounts to 60–75 per cent.

Figure 6 illustrates the abundance and varying size of the nodules, and the thickness and discontinuous character of the tan laminations. Most of the nodules are elliptical in shape, being somewhat elongated parallel to the bedding. It seems evident from the curved distortion of the laminae in the black shale surrounding the nodules, that these nodules have grown to their present size subsequent to the deposition of the organic shale in which they are enclosed. Sections across some of the large nodules, from ¼ to 1 inch in diameter, reveal that in general the central portion has a medium gray color and is surrounded by an outer border of tan color that apparently has resulted from alteration of the original dark gray material. It has been noted in many instances that the tan-colored material has a porous and sometimes oölitic texture.

The nodular shale contains an average of 1.69 per cent of phosphorus, 8.45 per cent $Ca_3(PO_4)_2$. In view of the comparatively small amounts of phosphorus in plant material, the abundance of this element in this instance suggests that it has become concentrated by marine animals from their plant food; its occurrence as nodules and laminations in the oil shale presumably is due in large part to the decomposition of the bones and excretory material of an abundant animal life. This suggestion is supported by the identification, mentioned in following pages, of coprolites in thin sections of this shale, and by the common occurrence of fossil bones and scales of fish.

MICROSCOPIC FEATURES

No exhaustive microscopic study of the nodular oil shale has been made, although numerous thin sections have been examined for unusual features. It appears that this shale body is remarkably uniform throughout. The two most striking microscopic features are the presence of abundant distinct laminae and the large quantity of dark brown and amber-colored organic material that, to judge from its occurrence in the shells of *Foraminifera* and in other areas that apparently were once voids, is either a viscous liquid or a solidified substance that was once a liquid or gel.

Samples of the nodular shale were submitted to W. H. Bradley of the United States Geological Survey. After studying thin sections, Bradley has made the following comments.

My impression of the shale in general is that it compares with oil shales of really good quality in the Green River formation. It differs from those chiefly in the apparent abundance of material that was once either liquid or a somewhat fluid gel. It is even possible that this material, which appears entirely homogeneous and solid under the microscope, may be very nearly an oil now and is really a transitional stage between the organic matter having more definite shape and actual petroleum.

Bradley has contributed the following more detailed account of some of the microscopic features of this shale.

This report is based on a microscopic examination of thin sections cut from four samples that came from the following depths: 5,857–5,881 feet, 5,900–5,902 feet, 5,965 feet, and 5,996 feet. These particular samples were chosen because they represented approximately equal intervals of depth in the body of oil shale rather than because of any apparent differences in the hand specimens of the shale. From each sample sections were cut both normal and parallel to the bedding.

Organic Matter.—In general four kinds of organic matter were distinguished in my study of this oil shale. The first is a deep yellow or orange material such as makes up certain spore exines and a few other rare fragments whose original composition was apparently like that of the spore exines. This material is distinctly a solid and is bi-refringent. It appears to be made up of extremely minute parallel fibers.

The second kind of organic matter, which is the most abundant of any, is deep reddish brown and though it is essentially structureless it has quite definite boundaries especially in the larger pieces. It occurs as thin stringers and small irregular flat flakes or sheets and in small irregular flocculent masses. Fragments of this sort of organic matter range greatly in size. The largest are to be measured in a few millimeters whereas the smallest bits are hardly more than a few microns across. This organic matter apparently represents fragments of organisms, possibly various marine plants either fixed seaweeds or planktonic forms. It is apparently less altered than most of the other organic matter in the shale. Nevertheless, it undoubtedly has undergone some change from its original composition, as it has lost all cellular structure and is now homogeneous except for slight differences in color.

The third kind of organic matter is light amber in color and is more or less evenly diffused through the rock. It is feebly bi-refringent, perfectly clear and transluscent. It evidently has been at some time during its history either a liquid or a very fluid gel.[9] My opinion is that this material was probably formed soon after the deposition of the original ooze and was forced into all available pores during compaction of the sediment. The deep reddish brown material of the second sort mentioned appears almost to grade into this pale

[9] In later correspondence Bradley suggests that these types of organic matter may be actually fluid now and may be the soluble hydrocarbons that have been extracted with solvents. These soluble hydrocarbons are called "free oil" in this paper and are present in such quantity that they should be apparent in thin sections.

yellowish material. As the size of the reddish brown flocculent material decreases, it approaches both in color and clarity the perfectly clear yellow stuff of the third class. This yellowish material is quite plentiful in the shale but makes up a smaller proportion of the rock than the deep reddish brown matter.

The fourth kind of organic matter is a very dark reddish brown opaque homogenous stuff which occurs rather sparingly, filling cavities like the chambers of the foram shells. This stuff also appears once to have been either liquid or a quite fluid gel.[9] It resembles the so-called humic jelly which has been described in certain bog-head coals and French and Australian oil shales. Presumably it is quite closely related to the pale yellowish organic matter just described and like the yellowish material was probably derived by decomposition from the reddish brown fragmental organisms.

Coprolites.—Three types of structures which I regard as probably coprolites were found in all of the thin sections. The first type has the shape of rather short irregular lenses tapered much more abruptly toward one end than the other. These appear to be rich in organic matter and are deep reddish orange. They show no recognizable remains of organisms, except occasional parts of foram shells. However, they are not structureless and appear to consist of aggregates of reddish brown organic matter, fragments of various sizes and shapes mixed with a very small quantity of fine mineral grains and a little of the pale yellow organic matter. By analogy with the other types of coprolites they probably now consist largely of collophanite. The second type of coprolites is by far the largest and most plentiful. They have the form of rather irregular ellipsoids or lenses whose surfaces are somewhat billowy (Fig. 7). These lenses are visible in the hand specimen as small light gray specks elongated parallel to the bedding. They appear to consist almost exclusively of collophanite which has so many shrinkage cracks that it might well be described as having a perlitic structure. All of this sort of coprolite are rather pale straw-colored and apparently were impregnated by a small amount of the light yellow or amber organic matter. A few of these coprolites contain nearly complete organisms.

The third type of coprolite is in general smaller and less common and consists predominantly of an aggregate of very fine mineral grains. Many of them are either cylindrical or ellipsoidal and quite sharply defined. The mineral grains in these coprolites are distributed utterly without order or arrangement and are mixed with shreds of more or less carbonized organic matter of various sizes and a rather plentiful supply of pyrite granules. These coprolites apparently were formed by mud feeders. They resemble somewhat a group of small coprolites that I found in silicified algae reefs in the Green River formation.

Organisms.—Foram shells of various types are rather common in all the thin sections and are distributed rather uniformly through the rock (Fig. 8). The chambers of some of these are filled with nearly opaque reddish brown organic matter that appears once to have been nearly fluid. Even the pores in the foram shells are colored with a similar kind of organic matter. A few of the foram shells have been filled with pyrite like some of those found in the recent muds in the Gulf of Maine. In some forams it appears that the interior was coated with pyrite first and the remaining cavity later, perhaps during compaction, filled with organic matter.

Fig. 7.—Photomicrograph showing coprolite of second class mentioned in report. It is shown in upper part of picture and thin section is cut normal to the bedding. ×135. By W. H. Bradley.

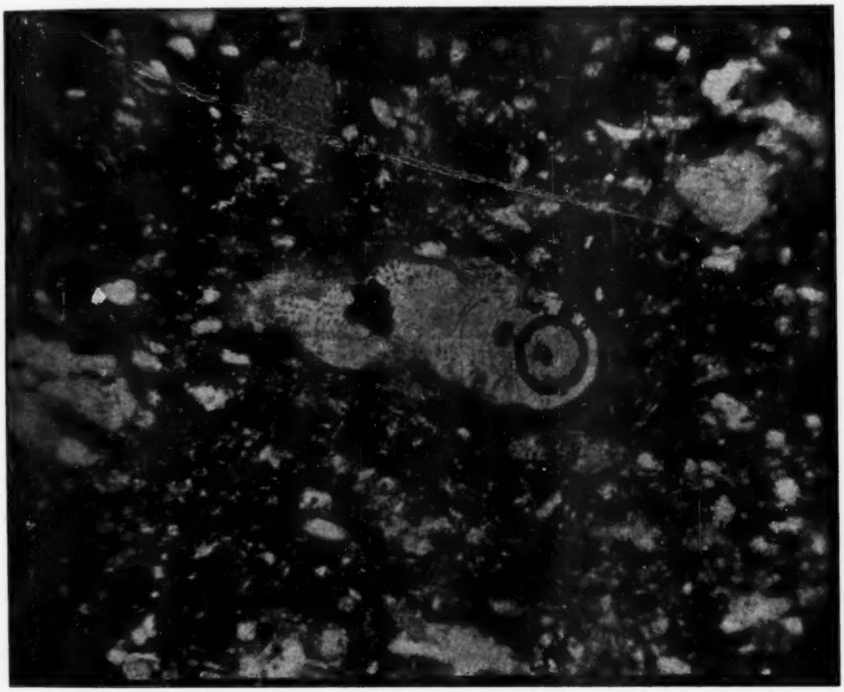

Fig. 8.—Photomicrograph showing foraminifer shell sectioned in such a way as to show pyrite lining of one of the cells and subsequent filling of cavity by organic matter. ×135. By W. H. Brady.

One organism may possibly be a radiolarian but I am not at all sure of its identification. It has a thin spherical shell which is adorned with moderately long tapering spines. Both the cell wall and the spines range from light reddish brown to straw color. If the original organism was siliceous, it apparently has been stained by the liquid organic matter. The interior of this shell is filled with cryptocrystalline silica.

A few waxy spore exines like those produced by certain ferns and mosses were found. These are much compressed and the original exine has been changed over into a dense homogeneous orange-colored solid which shows many shrinkage cracks. It is feebly bi-refringent and contains numerous minute pyrite granules. In addition to these spores the only other organisms that apparently have their original forms are some small spherical spore-like bodies that are brown or reddish orange in color. These range from about 7 to 9 microns in diameter and are rather common. They may possibly be resting spores of some sort. A few minute ellipsoidal spores resembling certain fungi spores were also found.

In one thin section I found a fragment of reddish leathery organic material which resembled the fragment of an alga thallus. It was covered with a coarse reticulation of thickening ridges.

Lamination.—In those sections cut normal to the bedding I found in places a more or less well defined lamination consisting of laminae alternating rich and poor in organic matter (Fig. 9). These are analogous, I believe, to the laminae found in the oil shale of the Green River formation, in the Upper Cretaceous rocks of the Black Hills by Rubey, and in the deposits of certain modern lakes. It appears to me that by analogy with these other deposits they are probably varves. Each varve, according to my interpretation, consists of one layer rich in organic matter and one poor in organic matter. My inference is that the layer rich in organic matter was formed in the summer when the pelagic organisms of the sea increase enormously and contribute much organic matter to the bottom deposits. Accordingly the layer poor in organic matter is the normal silt deposit which comes down during the rest of the year when the organic life is less abundant. I measured in all 20 of these pairs of laminae and they average about 0.025 of a millimeter thick. The thinnest ones are only about 0.009 of a millimeter thick and the thickest ones are about 0.065 of a millimeter thick. The average thickness is very nearly identical with the thickness of the varves which I described in the Green River formation. The thinnest ones, however, are thinner than any I found even in the richest oil shale beds.

THE AMOUNT AND DISTRIBUTION OF FREE OIL

Retort tests have been made on samples taken from cores of the nodular oil shale, the overlying Miocene shale, and the Lower Pliocene clay shale. The following table contains a tabulation of the amount of total oil obtained from each of these samples and reveals the fact that with the exception of two minor parts of the overlying Miocene shale, the nodular shale is the only stratigraphic unit that contains large quantities of oil or organic material which yields oil upon distillation. Much the greater part of the oil obtained from samples of the Lower Pliocene and most of the immediately underlying Mio-

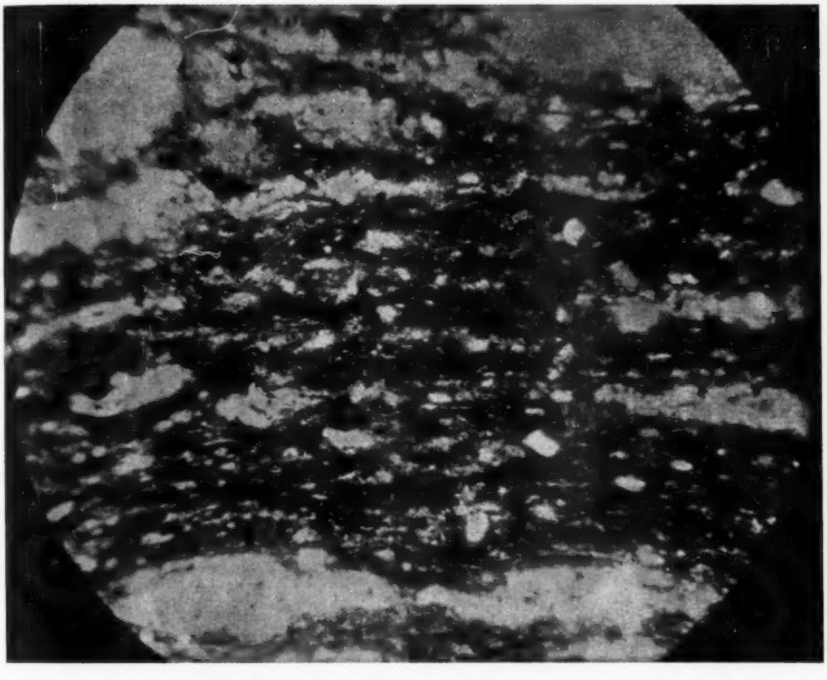

FIG. 9.—Photomicrograph showing lamination of oil shale. Darker layers are rich, lighter layers are relatively poor, in organic matter. ×120. By W. H. Bradley.

TABLE IV

RESULTS OF RETORT TESTS ON PLIOCENE AND MIOCENE SHALES BEFORE EXTRACTION

Sample No.	*Geologic Subdivision*	*Distance above Base of Respective Geologic Subdivision (Feet)*	*Oil per Ton of Shale by Retorting before Extraction with Chloroform (Gallons)*	*Free Oil per Ton of Shale Obtained by Extraction with Chloroform (Gallons)*
1		1,723–1,740	0.9	
2		1,524–1,554	1.2	
3		1,403–1,414	Trace	
4	*Pliocene*	891– 900	Trace	
5	Repetto formation	383– 400	0.9	
6		200	0.9	
7		150	0.9	
8		100	1.2	
9		50	2.1	
10		464 (top)	1.2	
11		414	1.5	
12		364	3.0	
13	*Miocene*	314	3.0	
14	Modelo formation (upper unit)	264	0.3	
15		214	0.6	
16		140	2.4	
17		115	3.0	
18		75	4.5	
19		24	10.2	
20		165 (top)	9.0	
21	(Middle unit)	125– 165	8.4*	2.55
22	Nodular oil shale	90– 125	11.4*	3.95
23		50– 90	13.2*	4.55
24		0– 50	15.0*	6.05

* Composite samples of stratigraphic interval indicated.

cene resulted from the distillation of organic matter, the amount of free oil in most instances being so small as to be difficult to measure. The amounts of free oil[10] in the nodular oil shale, however, are appreciable. The data in the preceding table are shown graphically in Figure 10.

Character of the free oil.—The free oil extracted with chloroform from the nodular shale is a heavy, black, viscous substance, barely fluid at room temperature (Fig. 11). Uniformity in the character of the free oil is indicated by only slight variations in the gravity and sulphur analyses of oil obtained from the top, middle, and bottom of the nodular shale; the specific gravity varies from 1.01 to 1.07 and the sulphur content from 4.31 to 5.02 per cent. These results may be taken as an indication that the free oil scattered throughout this shale deposit is substantially the same material. One sample of the ex-

[10] The term "free oil" is used for chloroform-soluble material which presumably is largely free oil.

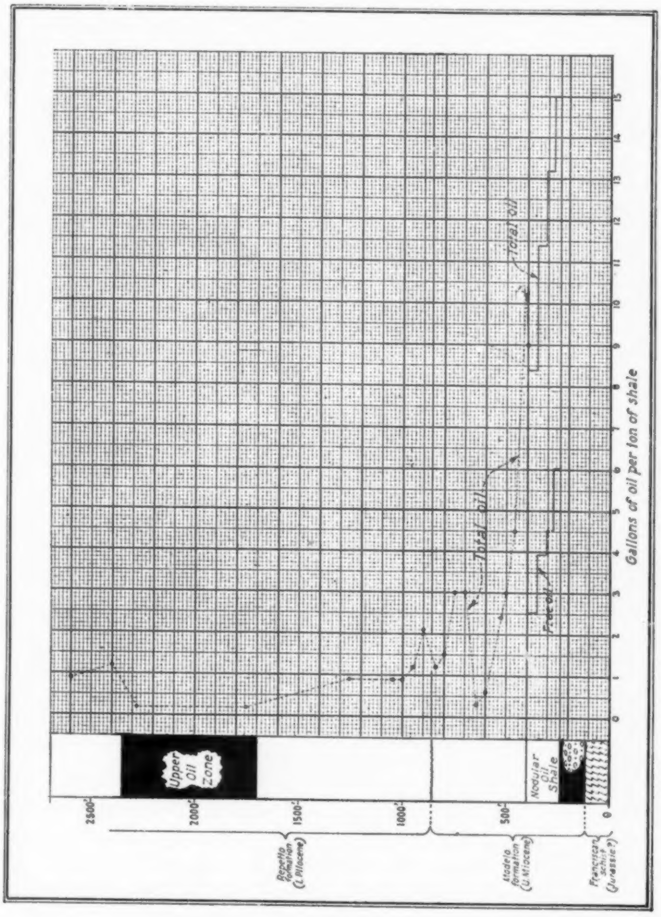

FIG. 10.—Chart showing distribution of free oil and total oil in Pliocene and Miocene shales.

tracted free oil taken from near the middle of the nodular shale has been analyzed and found to have the following composition.

ANALYSIS OF EXTRACTED OIL

	Per Cent
Carbon	74.7
Hydrogen	8.4
Sulphur	4.3
Nitrogen	1.3
Oxygen	7.8
Chlorine (from re-	1.8
sidual chloroform)	1.8
Ash	1.7

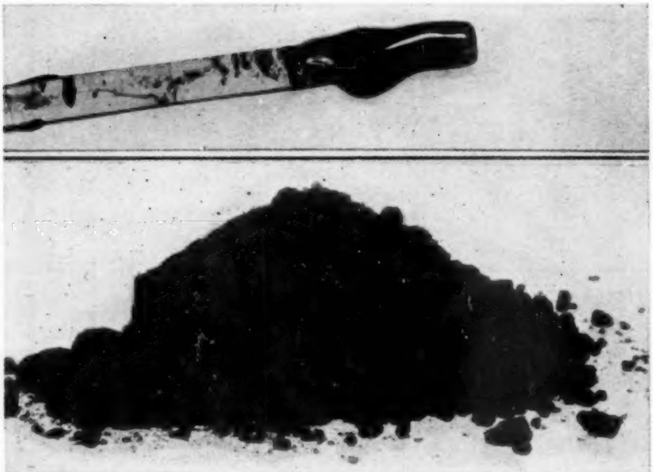

FIG. 11.—Upper photograph is of glass rod to which is clinging some of the black viscous free oil extracted by solvents from nodular shale. Lower photograph shows black, powdery, petroleum ether-insoluble material present in free oil of nodular shale. About natural scale. Photographs by K. E. Lohman.

The oxygen content is of particular interest, since it indicates the presence of an appreciable amount of oxygenated compounds such as petroleum acids, esters, pyrobitumens, and waxes. The results of the carbon-hydrogen analyses will be used in a later portion of this paper.

Microscopic evidence warrants the statement that a structureless, brown substance, apparently oil, is present in the nodular shale and that it probably has been derived from associated organic matter. From this evidence and the fact that the heavy viscous free oil extracted from the shale is radically different from the crude oil in the

underlying lower oil zone, it appears reasonable to conclude that this free oil is indigenous to the nodular shale; the character of the free oil suggests that it may be merely a residual remnant of the oil originally formed in this shale; additional evidence to support this suggestion is presented in following pages.

In order to make some reasonable chemical comparison between the extracted free oil and the Playa del Rey crude from the lower zone, a distillate was obtained from each of these materials within a distillation range of 200–600°F. A hydrocarbon analysis was made on each of these distillates with the following results.

TABLE V

Nature of Sample	*Grav. °A.P.I.*	*Unsaturates Per Cent*	*Aromatics Per Cent*	*Naphthenes Per Cent*	*Paraffines Per Cent*
Distillate from crude from lower zone at Playa del Rey	41.9	5.5	19.2	52.0	23.3
Distillate from oil extracted from Playa del Rey shale	28.7	19.1	30.8	39.6	10.5

The results set down in the foregoing table do not indicate that the Playa del Rey crude and the extracted oil from the nodular oil shale contain similar material within the 200–600°F. boiling range. These results might be expected if the oil now in the nodular shale were a residual material left in the shale from a previous migration of a part of the original oil.

Large-scale laboratory extractions of the free oil from four composite portions of the nodular oil shale deposit have been made. The complete removal of the chloroform from the oil obtained from these large samples was not accomplished, due to the fact that the heavy residue entrapped part of the chloroform and practically made its removal impossible without subjecting the oil to relatively high temperatures which would be expected to alter its character. In order to remove the heavy asphaltic material and thus make possible a more complete removal of the chloroform from the less viscous light-oil and lubricating-oil fraction, an expedient was tried which consisted of extracting the extracted oil, containing a small amount of chloroform, with petroleum ether. This was successful except that, surprising as it was, there was obtained a relatively large amount of material insoluble in petroleum ether.

The following table presents the results of the various extraction and distillation tests on composite samples representing four parts

of the nodular shale, and it also gives the percentages of the petroleum ether-soluble and insoluble material in the oil extracted from the shale with chloroform. These latter results were obtained by extracting with petroleum ether portions of the oil obtained from the large samples of the core and weighing the residue.

TABLE VI
RESULTS OF EXTRACTION AND DISTILLATION TESTS ON COMPOSITE SAMPLES OF NODULAR OIL SHALE

Sample No.	*Depth below Top of Nodular Shale (Feet)*	*Total Oil by Distill. (% by Wgt.)*	*Oil by Extraction (% by Wgt.)*	*Oil from Kerogen (% by Wgt.)*	*Pet. Ether-Soluble Material in Extracted Oil (% by Wgt.)*	*Pet. Ether-Soluble Oil in Original Shale (% by Wgt.)*	*Pet. Ether-Insoluble Oil in Extracted Oil (% by Wgt.)*	*Pet. Ether-Insoluble Oil in Original Shale (% by Wgt.)*
1	0– 45	3.36	1.02	2.34	61.3	0.63	38.7	0.39
2	45– 83	4.56	1.58	2.98	50.5	0.80	49.5	0.78
3	83–125	5.28	1.82	3.46	37.2	0.68	62.8	1.14
4	125–182	6.00	2.42	3.58	45.0	1.09	55.0	1.33
Average (Weighted)	0–182	4.88	1.76	3.22				

As is shown in the foregoing table, the amounts of petroleum ether-soluble oil at the different depths vary considerably and generally increase with depth; the amounts of petroleum ether-insoluble material are even more widely divergent and have a more definite increase with depth.

The petroleum ether-insoluble material in the oil extracted from the shale with chloroform is a black powdery substance (Fig. 11) high in carbon and containing 17.2 per cent oxygen, 4.1 per cent sulphur, and 1.83 per cent nitrogen. It is estimated that practically all of the oxygen present in the extractable oil is contained in this insoluble material, and it appears that the percentage of sulphur in Venice crude is approximately the same as that in the insoluble material and that the nitrogen content of the insoluble material is not unusual for a natural bitumen. Little can be said concerning the significance of these features, but the physical characteristics of this abundant petroleum ether-insoluble material suggest that it, of all the constituents of a newly generated oil, would probably be the first to be left behind during the migration of the oil from the nodular shale. Evidence has already been presented in support of the belief that the extractable oil containing this petroleum ether-insoluble material is indigenous to the nodular shale, and the suggestion has been made that this extractable oil is merely a remnant of the oil

originally formed in this shale body. Had the original oil migrated from the nodular shale downward to the contiguous conglomerate, the present lower producing oil zone, it is reasonable to suggest that as this oil passed through the fine-textured nodular shale, its heaviest fractions might readily be retained by the shale due to adsorption or some similar phenomenon, and would tend to accumulate in greater amounts toward the bottom of the shale body. The general increase in the amount of heavy viscous free oil with depth in the nodular shale and the even more consistent increase in the amount of the petroleum ether-insoluble material with depth (see column 8 in Table VI), supports the suggestion that such migration has occurred. The following tabulation offers similar support for this suggestion from the fact that the ratio of free oil to kerogen increases in the nodular shale with depth.

TABLE VII

Nodular Shale Composite Sample	*Depth below Top of Nodular Shale*	*Free Oil by Extraction (% by Wgt.)*	*Oil from Kerogen (% by Wgt.)*	*Ratio of Free Oil to Kerogen*
1	0– 45	1.02	2.34	.44
2	45– 83	1.58	2.98	.53
3	83–125	1.82	3.46	.53
4	125–182	2.42	3.58	.68

It might be reasoned that a similar increase in the amount of petroleum ether-insoluble material with depth would be present if oil had migrated upward from the lower producing zone through the nodular shale bed. If this had occurred, the free oil present in the upper portion of the shale bed would be expected to be lighter and more volatile than Playa del Rey crude, which is not the case.

Summarizing the evidence obtained from a study of the free oil contained in the nodular shale, it may be said that (1) free oil is present in appreciable quantities throughout the shale and increases in amount toward the base; (2) this heavy viscous free oil is radically different in physical and chemical character from the Playa del Rey crude and is believed to be indigenous to the nodular shale and to be merely a residual remnant of the oil originally formed in this shale; (3) the free oil contains a large amount of material insoluble in petroleum ether; and (4) the downward increase in the amount of total free oil, the material insoluble in petroleum ether, and particularly in the ratio of free oil to kerogen, suggest that downward migration of oil through the nodular shale to the underlying oil sand has occurred.

OIL BY DISTILLATION

Pyrobitumen or kerogen is that organic matter present in some shales which when heated yields oil. A considerable quantity of this material is present in the nodular shale associated with free oil. To determine the quantity of oil obtainable only from the kerogen, four composite samples of the nodular shale were distilled in an iron retort substantially according to the method described by the U. S. Bureau of Mines.[11] The percentage of oil obtainable from the kerogen was computed by deducting from the total percentage of oil obtained during the retorting test the percentage of oil extracted from the original shale with chloroform. The results of this computation are set down in column 4 of Table VII.

It is thought that the oil obtained by distillation of the shale is not representative of any portion of oil that could have been obtained by decomposition of the organic matter under natural conditions, due to different temperature, pressure and time conditions. It also seems probable that the kerogen now present in the shale is a residual material remaining from a previous decomposition of the original organic material present in the shale, and, therefore, that the oil obtained by pyrolysis of the present shale need not be similar to the oil that would have been obtained by similar treatment of the original undecomposed kerogen. For these reasons, no attempt will be made to compare the distilled oil with Playa del Rey crude or with a fraction from this crude.

CARBON-HYDROGEN RATIO OF THE SHALE

In the earlier work on this investigation an attempt was made to determine whether the organic material in the nodular oil shale is a residual material and whether the shale previously contained more oil than it now contains. It was thought that the carbon-hydrogen ratio of the shale after the removal of extractable oil might be used as a measure of the degree of decomposition of kerogen and subsequent migration of oil that had occurred. It was reasoned that the decomposition of the kerogen under natural conditions would be attended by the formation of a carbonaceous residue similar to that which forms during the Bureau of Mines distillation of shale and that if it were shown that the organic material other than oil now in the Playa del Rey shale had an abnormally high carbon-hydrogen ratio, this would be evidence of decomposition. This evidence, together with the amount of oil computed to have been formed during the decomposition and the amount of free oil now found to be associated with the shale,

[11] *U. S. Bur. Mines Bull. 249.*

would be a basis for substantiating the hypothesis that oil had formed from the original kerogen and that part of it had left the shale bed. Some interesting results were obtained along this line, but the information first used was based on determinations made by the customary carbon-hydrogen analysis of samples of Playa del Rey nodular shale and reported information on the analyses of shales from various parts of the world. Subsequent work has shown that it is not possible by a simple combustion analysis to obtain reliable results as far as the hydrogen content of kerogen is concerned, because water present, both as water in the organic matter and as water of crystallization in clay minerals, is not accounted for by the regular analytical procedure. Some recent work indicates that we may be able to determine the amount of hydrogen from these sources obtainable from the acid-treated, extracted shale and to correct the carbon-hydrogen analysis for the hydrogen in this water. The carbon-hydrogen ratio in the nodular shale, without making the necessary correction for hydrogen, is 8.25 and is somewhat higher than the average of the values for various oil shales throughout the world as reported in the literature.[12] Probably these latter analyses were not corrected for any combined water that might have been present. Because of the absence of this correction, no great importance can be attached to the relatively high carbon-hydrogen ratio of the nodular shale from Playa del Rey. The results of the carbon-hydrogen analysis of the acid-treated, extracted nodular shale, when a correction is made for the hydrogen in the water of organic matter and clay minerals indicate that the kerogen has a carbon-hydrogen ratio of 15.4.[13] This result will be significant only, however, when analyses have been made on samples of other oil shales from various parts of the world. A high carbon-hydrogen ratio for the nodular oil shale at Playa del Rey, when compared with oil shales from other regions that apparently have contributed no appreciable amount of oil, should constitute evidence that the carbon-hydrogen ratio of this shale had been disturbed by the destruction of organic matter to form free carbon and oil and gas, and by the loss of the oil and gas.

Downward Migration

The lower oil zone of Playa del Rey, resting directly upon an old bed rock of Jurassic schist, comes close to being a definite example of downward migration of oil. Certainly nothing more definite could be expected by those who believe that commercial deposits of oil

[12] See Ralph McKee, "Shale Oil," p. 77.

[13] The method used for the determination of carbon and hydrogen is presented on pp. 293–95 of this bulletin.

originate within or directly adjoining the areal limits of producing fields. With no possible source beds below the lower producing zone and with a striking probable source bed directly overlying it, there appears to be no possibility that upward migration has occurred within the field.

The conglomeratic lower oil zone is believed to be Miocene and obviously must be separated from the underlying Jurassic schist by a major unconformity representing the time during which Cretaceous, Eocene, and Oligocene beds accumulated in other districts. Many thousands of feet of conglomerate, sandstone, and shale belonging to this missing interval occur in the Santa Monica Mountains 5–10 miles north of the Playa del Rey field. It may be argued that these beds are likely source beds and that oil from them may have migrated laterally along the unconformity and into the lower oil-zone conglomerate of Playa del Rey. Similar arguments can be made for the probable unconformity at the top of the lower oil zone conglomerate, and for the one at the top of the Miocene.

It is impossible to refute contentions of this type but when such remote possibilities are compared with that presented by the nodular oil shale—a marine unit 150 feet thick, rich in bitumen and kerogen, and resting in contact with a producing oil zone—a choice is not difficult.

Geological conditions at Playa del Rey appear to have been particularly favorable for downward migration. The source bed of oil shale is overlain by several hundred feet of hard dense siliceous shale that served as an impervious cap rock and is directly underlain by a coarse conglomerate of sandstone into which oil from above could readily enter. Regardless of whether the oil was distilled by pressure or was formed chiefly through biochemical action, it is reasonable that it would migrate into adjoining permeable voids. The underlying conglomerate provided the only ones, at least until faulting developed.

The authors believe it probable that the oil in the upper zone, lying within the Pliocene and some 1,500 feet above the nodular oil shale, migrated upward along fractures from either the nodular oil shale or the lower oil zone conglomerate. The similarity of the crude oils of the two zones is the chief reason for this belief. Their specific gravities and sulphur contents are almost identical, while other characteristics are similar and vary no more than might be expected from the influences of migration. The identical sulphur percentages of the two crudes are strongly suggestive that these oils originated in the same bed or in beds having the same sulphur-organic matter ratio. By this line of evidence the Pliocene would be an unlikely source for

this oil since its sulphur-organic matter ratio is much higher than that of the nodular shale—the source rock for the lower zone oil.

Summary

Stratigraphically downward migration of oil appears almost certain from the fact that a producing oil zone of Miocene conglomerate rests directly upon highly metamorphosed schist (Jurassic?).

The following facts influence the authors to consider it probable that the nodular oil shale has been the source of Playa del Rey oil.

(1) It is by far the most highly organic horizon in the stratigraphic section of the Playa del Rey oil field.

(2) It occupies a position directly overlying one of the oil zones which would have permitted comparatively easy migration into this zone.

(3) The crude oil and the shale are similar in that they both contain an unusually large amount of sulphur.

(4) The areal distributions of the nodular oil shale and high sulphur oils are similar.

(5) The shale contains not only considerable organic matter which yields oil upon heating, but also considerable free oil.

(6) In physical and chemical nature this free oil is strikingly different from the crude oil in the underlying oil zone and is believed to be indigenous to the nodular oil shale and to have been derived from comparatively unstable types of organic matter. This shale has a similar character and free oil content in outcrops 7 miles from producing fields, where there appears to be no possibility that the free oil has migrated into the shale from an adjoining porous sandstone.

(7) Both the crude oil and the free oil in the shale contain important amounts of a heavy asphaltic substance insoluble in petroleum ether, but the free oil in the shale contains a much greater amount. This fact, together with the heavy viscous nature of the free oil, indicates that the free oil in the shale may be a remnant of the oil originating there and may have resulted from migration of the lighter fractions to the underlying sand.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 206-220, 13 FIGS.

CHARACTER AND POSSIBLE ORIGIN OF PRODUCING ROCK IN HILBIG OIL FIELD, BASTROP COUNTY, TEXAS[1]

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Princeton, New Jersey

ABSTRACT

An introduction giving the location of the field and, in brief, the conditions existing at Hilbig is followed by a short résumé of Texas rocks of this general type. The character and origin of the Hilbig mass are discussed with the conclusion that it is a fragmental volcanic rock classed as palagonite tuff and palagonite lapilli tuff.

INTRODUCTION

The purpose of this paper is to describe the character of the producing rock in the Hilbig field and to suggest its probable origin as indicated by the character of the material.

ACKNOWLEDGMENT

The writers wish to express special appreciation to F. W. Rolshausen, paleontologist with the Humble Oil and Refining Company, who has coöperated in every possible way in furnishing material and in criticizing ideas submitted to him. Thanks are due to the Humble Oil and Refining Company for allowing the use of material and data gathered wholly by their staff. Professor A. F. Buddington, of Princeton University, has assisted in the examination of thin sections and in the determination of the character of the material. Clarence S. Ross, of the Petrology Section of the United States Geological Survey, has kindly checked the determination of the major material as palagonite, and also the tabular phenocrysts in the fragments of some of the beds as being melilite. The writers are indebted to John Smithies of Princeton for running magnetic-susceptibility determinations.

[1] Manuscript received, June 8; revised, December 17, 1934.

[2] Princeton University.

[3] Princeton University. Present address, Lakeside Irrigation Company, Inc., Eagle Lake, Texas.

LOCALITY

The Hilbig field is located in Bastrop County, 9 miles southwest of the town of Bastrop (Fig. 1). It is a small field with an area of approximately one square mile.

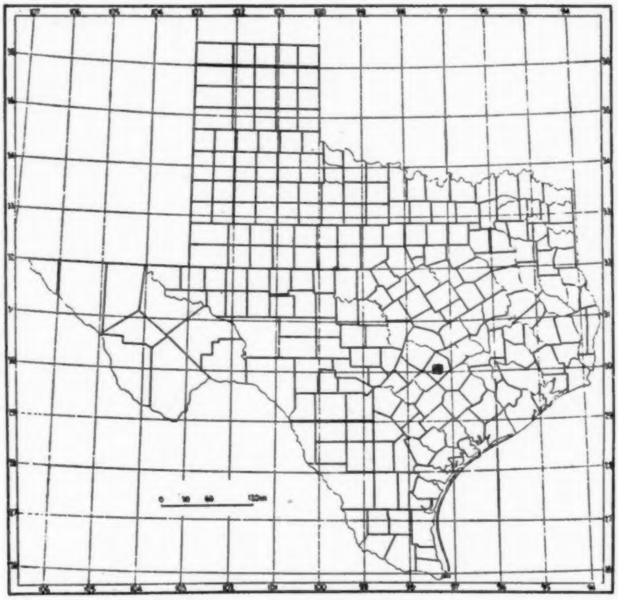

FIG. 1.—Location map, Hilbig field, Bastrop County, Texas.

STRATIGRAPHIC SECTION

The field is producing from porous volcanic rock which lies partly within the Austin chalk. Most of the Austin lies entirely beneath the volcanic rock, but there is some overlap of the chalk around the edge of the dome-like mass. The central portion of the body is in direct contact with the Taylor formation above, and the Taylor undoubtedly acted as a source bed for the petroleum (Figs. 3, 4, and 5).

The stratigraphic section, as indicated by the microfossils, includes all the representative formations of this area. Beginning with the Wilcox, which is the outcropping formation at the field, the formations and their thicknesses are as follows.

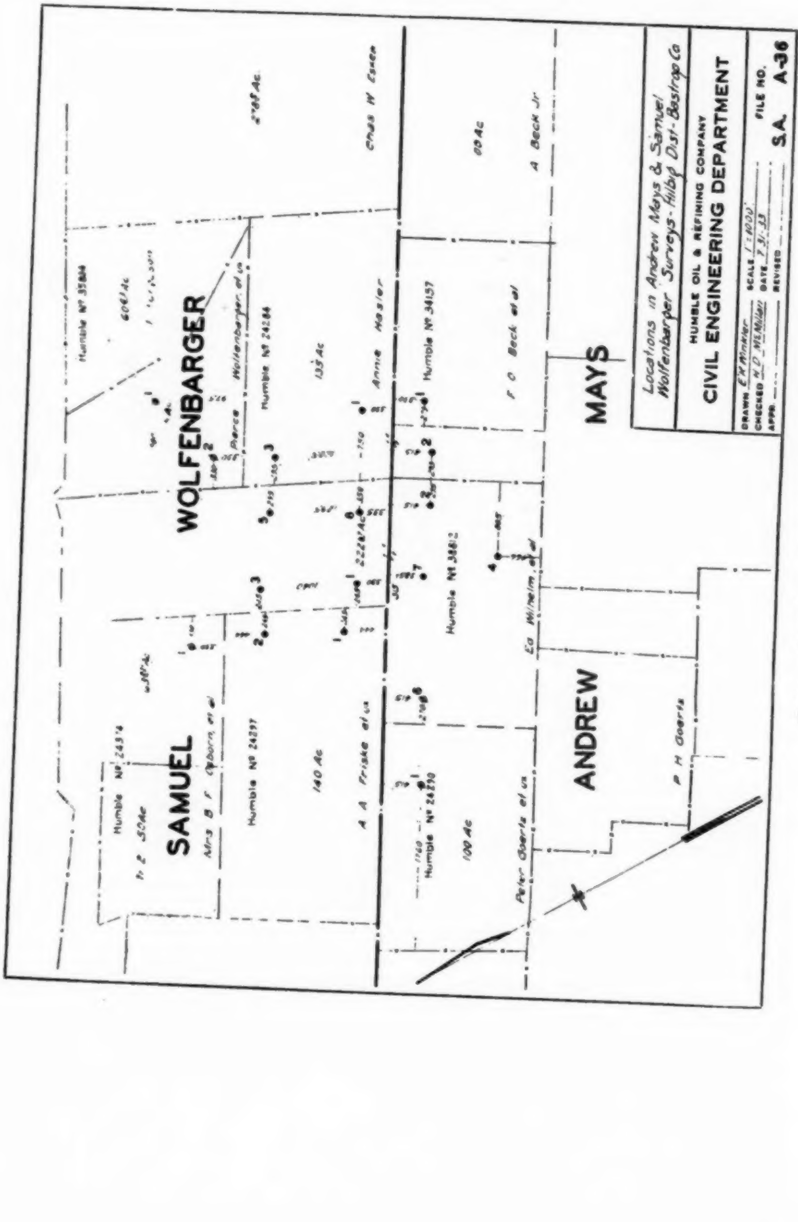

FIG. 2.—Location of wells mentioned within field.

A petrographic study of the rock indicates that it is in general similar in character and origin to the producing formation in other fields, for example, the Thrall and Lytton Springs fields in Williamson and Caldwell counties, respectively. However, certain character-

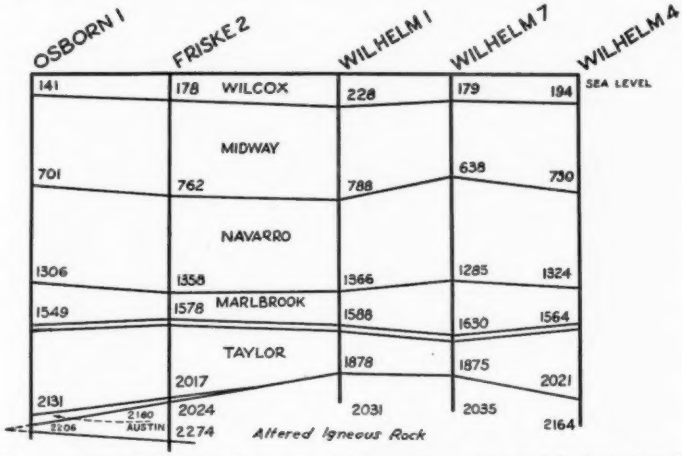

FIG. 3.—North-south subsurface cross section. Same vertical and horizontal scale. Depths in feet. Locations of wells are shown in Figure 2.

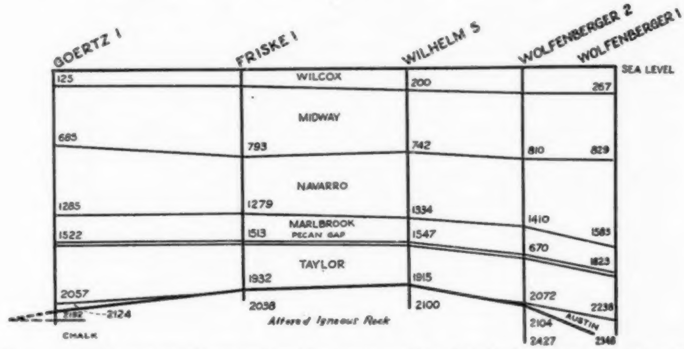

FIG. 4.—Southwest-northeast subsurface cross section. Vertical and horizontal scale same. Depths in feet. Locations of wells are shown in Figure 2.

istics indicate that the rocks of each field vary somewhat in details of structure and origin. The character of the rock has been determined by a petrographic study of well cores. The theory of origin proposed here is based on the character of the material, shape of

the mass, and its relation to the adjacent rocks. The general field relationships are shown in the series of cross sections based on drill findings (Figs. 3, 4, and 5).

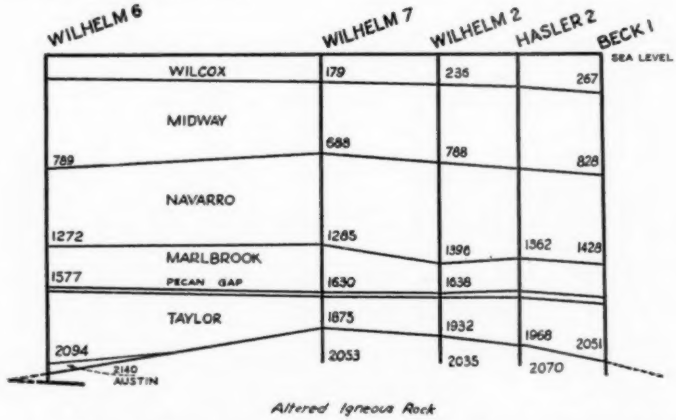

FIG. 5.—West-east subsurface cross section. Vertical and horizontal scale same. Depths in feet. Locations of wells are shown in Figure 2.

		Feet
Eocene	Wilcox	200
	Midway	500–550
Upper Cretaceous	Navarro	600–700
	Taylor*	600–800
	Austin	100

* Taylor includes the Pecan Gap and Marlbrook division.

PRODUCING ROCK

MEGASCOPIC

Megascopically, the producing rock is dull-to-dark green in color, and fragmental, containing varying quantities of calcareous material as part of the matrix. The calcareous material is more abundant in rock consisting of larger fragmental constituents. Some specimens show inclusion of chalk not noticeably metamorphosed (Fig. 6). Other specimens show definite bedding of coarse and finer materials (Fig. 7). The variation in size of the fragments is considerable; the smaller, finer particles are well within the 4-mm. maximum for tuff, and the larger particles range into sizes characteristic of lapilli tuff. Following the terminology of Wentworth,[4] the terms "tuff" and "lapilli tuff" are applied.

[4] Chester K. Wentworth, and Horvel Williams, "The Classification and Terminology of the Pyroclastic Rocks," *Nat. Research Council Bull. 89* (1930–32).

MICROSCOPIC

Preceding the description of the specimens of the rock as they appear in thin section under the microscope, the significance of the term "palagonite" may first be briefly noted. Palagonite[5] generally denotes hydrated basic glass. The color in thin section is brown, green, orange, or yellow. The material is usually crypto-crystalline, and may show spherulitic, fibrous, concentric, radiate or vermicular-like crys-

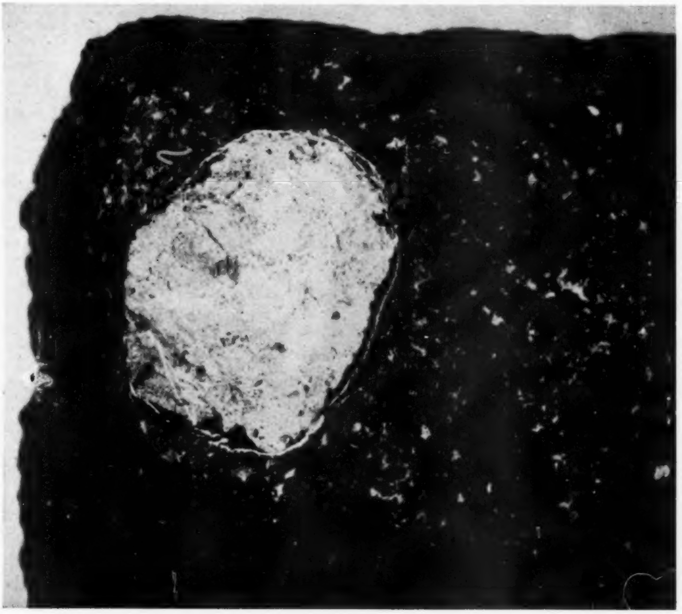

FIG. 6.—Photograph of core sample, Wilhelm No. 7, between 2,282 and 2,305 feet, showing inclusion of chalk in volcanic rock. Chalk is indurated, non-crystalline. $\times 2\frac{1}{2}$.

tallizations, or may be in part isotropic. It is commonly associated with alteration products which may occur as spherulitic crystallizations, amygdule fillings, or in irregular fashion, including such green minerals as celadonite, glauconite, chlorites, as well as with zeolites. Palagonite occurs typically as alteration of glassy pyroclastics of

[5] M. A. Peacock and R. E. Fuller, "Chlorophacite, Sideromelane, and Palagonite from the Columbia River Plateau," *Amer. Mineralogist*, Vol. 13, No. 7 (1928).

basic composition, and was first described by von Walterhausen from tuffs of marine origin. Peacock and Tyrrell[6] state that

palagonite is essentially a hydrogel of sideromelane, the hydration being accompanied by an almost complete oxidation of iron and a partial loss in some soluble form of lime and soda.

All the characters just described for palagonite in general fit the bulk of the material which forms the rock under consideration. The palagonite is commonly vesicular, with the vesicles filled with calcite or a greenish birefringent, strongly pleochroic, fibrous mineral. Spherulitic alterations are also common.

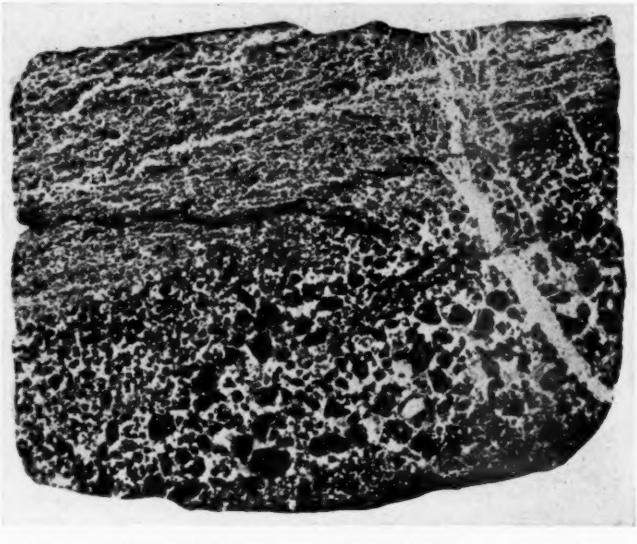

FIG. 7.—Photograph of core sample from Friske No. 2, at 2,480 feet, showing distinct stratification in matrix of carbonate. $\times 2\frac{1}{2}$.

Locally, vugs between fragments may be filled with a crusted microspherulitic aggregate of a similar greenish mineral, or with crusts of calcite and quartz. The proportion of micro-crystals in the rocks is variable. In some sections they are sparse; in others there are abundant tabular crystals of what is probably melilite. These show, in rectangular sections cut at right angles to the short axis, a characteristic structure oriented at right angles to the long axis,

[6] M. A. Peacock and G. W. Tyrrell, "The Petrology of Iceland," *Trans. Royal Soc. Edinburgh*, 55 (1926). p. 69.

FIG. 8.—Photomicrograph of thin section, Friske No. 2, between 2,600 and 2,620 feet. Light-colored bladed phenocrysts are altered melilite in palagonite groundmass with vesicles filled with microspherulitic greenish mineral. ×20.

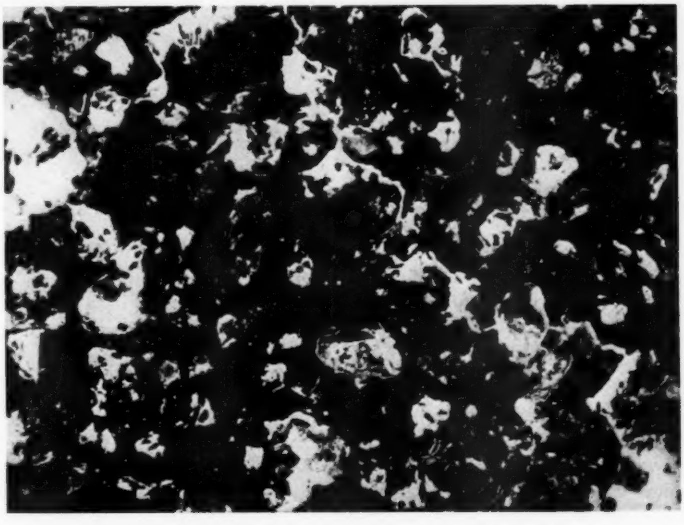

FIG. 9.—Photomicrograph of thin section of porous palagonite tuff, Goertz No. 1, between 2,568 and 2,588 feet. ×20.

commonly with a central parting line. They are greenish in color, due to alteration. Iron ore particles, in part magnetite, are common. Other crystals, perhaps originally pyroxene and plagioclase, have been replaced by carbonate and some other associated alteration products (Figs. 8 and 9).

Lonsdale[7] has compared the composition of the average basalt from the Balcones fault region with the composition of the average "serpentine" of the same region and finds that hydration is the

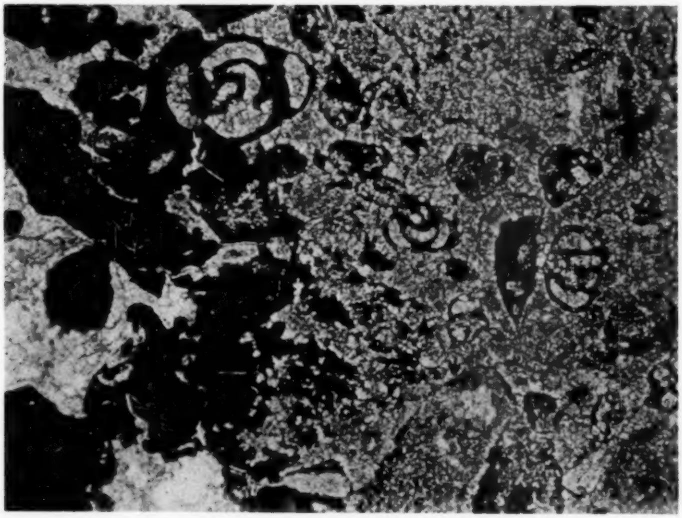

FIG. 10.—Photomicrograph of thin section, Wolfenbarger No. 2, at 2,622 feet. Inclusion of chalk in tuff in which micro-fossil sections are distinct. ×20.

dominant process, and that in addition there has been marked oxidation of the iron, and some loss of silica, magnesia, lime, soda, and potash. It may be noted that the process of palagonitization is in general dominantly one of hydration accompanied by oxidation of iron and loss of lime and soda, and is therefore consistent with the data presented by Lonsdale.

In some sections, as for example, one from the core of Wolfenbarger No. 2 at 2,622 feet, another from Friske No. 2 at 2,600 feet, there are unmistakable micro-fossil sections within the body which have become incorporated in the tuff (Figs. 10 and 11).

[7] J. T. Lonsdale. "Igneous Rocks of the Balcones Fault Region of Texas," *Univ. Texas Bull. 2744* (1927), pp. 134–35.

Briefly, the rock is altered basaltic tuff and lapilli tuff with inclusions of chalk and with infiltrated calcareous material.

MAGNETIC SUSCEPTIBILITY OF VOLCANIC ROCK

The magnetic property of the body is known through the use of the magnetometer in locating the field. However, measurements of its magnetic susceptibility made by means of the Frantz isodyne in the department of geology at Princeton University show a very striking contrast between the volcanic body and the surrounding chalk.

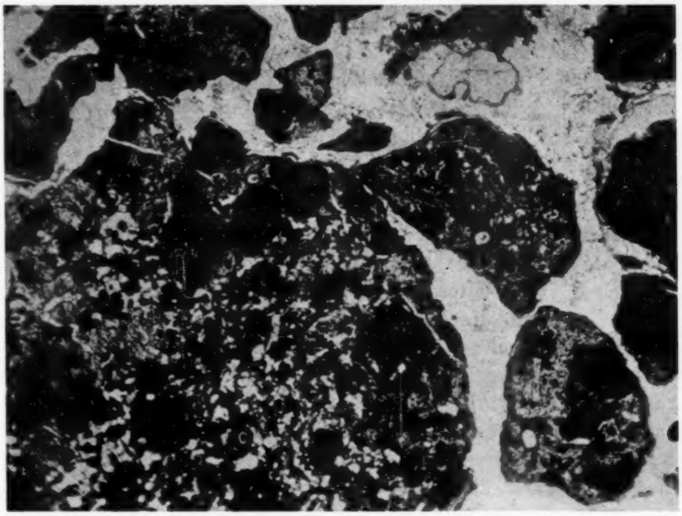

FIG. 11.—Photomicrograph of same section shown in Figure 10 enlarged. Palagonite fragments in carbonate matrix. Fossils also in this groundmass. ×20.

The magnetic susceptibility of the average sample of the volcanic rock shows $Km \times 10^6$ (Km—mass susceptibility) equal to 972 in cgs. (centimeter-gram-second) units at a field strength of 1,462 gauss; while an average sample of the surrounding chalk did not show sufficient susceptibility for exact measurement.

The high magnetic susceptibility of the volcanic rock as shown by these measurements results largely from considerable magnetite in the mass. The magnetic susceptibility of the chalk is unusually low, below that for the average calcareous rock or limestone.

NAME OF ROCK

The rock appears to belong to the same group which has in other fields been classified under the general term "serpentine."

The name "serpentine" has been frequently used in the Balcones fault area to designate green alteration products of basaltic rocks. In a strict sense, serpentine rock is composed dominantly of the mineral serpentine, which is an alteration product of magnesium-rich rock, and hence, its application. The greenish altered rock of this area which contains little or no serpentine technically should not be called such. However, well drillers in the Balcones fault region call such rocks "serpentine" and the name has become well established as a local field name, although Lonsdale called attention to the fact that the term is not specifically descriptive of the rock to which it is applied. The volcanic rock of the Hilbig field is locally called "serpentine," but the writers propose in this paper the use of the name "palagonite" as being more nearly descriptive of the actual character of the rock.

THEORY OF ORIGIN

Three theories have been offered to explain the origin of the altered basaltic rocks of the type here under discussion, that is, bodies resulting from the alteration of Cretaceous volcanic products with which oil accumulations are associated, namely: (1) that they are sedimentary, (2) that they represent a submarine volcanic cone in the sea which was depositing the formation with which they are associated, in which case they are altered tuff, ejectamenta, and flows; (3) that they are the result of alteration of both intrusive and extrusive rocks localized at the vent. The volcanic material at Hilbig is most consistent with the idea of a purely extrusive submarine origin.

As to the probable origin of the producing rock at Hilbig, the writers are of the opinion that it was the result of a submarine extrusion, and that intrusion played a very small part, if any. The character of the rock indicates an extrusive origin. 1. The rock has the fragmental texture and the stratified character of a tuff or lapilli tuff. 2. Micro-fossils are incorporated deeply within the material, as are also large fragments of chalk, which must have been incorporated from sediment on the floor of the Austin sea as the lava was extruded. 3. No contact metamorphism occurs in the Taylor where it is in direct contact above the volcanic material; and there is very limited incipient metamorphism of the Austin chalk, inclusions even occurring as wholly unaltered material. There is none of the intense metamorphosis associated with true intrusion as developed in the plug

bodies of Uvalde County. 4. The apparent structure of the Austin when it partially overlies the volcanic body can be accounted for through locally high angles of deposition, due to the existence of the dome-like mass contemporaneous with deposition; any structure in the higher beds could result from the same cause. 5. The porosity is a result of disintegration and gas expansion in the basaltic lava as it

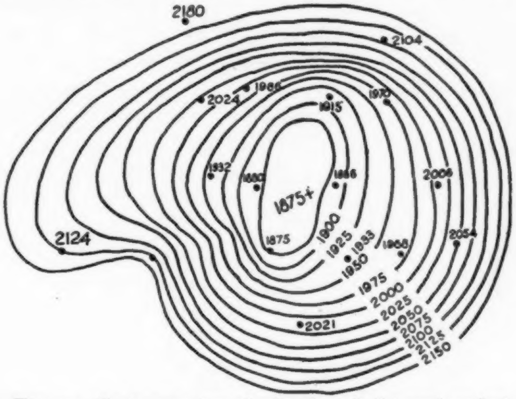

FIG. 12.—Contours on top of volcanic rock. Interval, 25 feet.

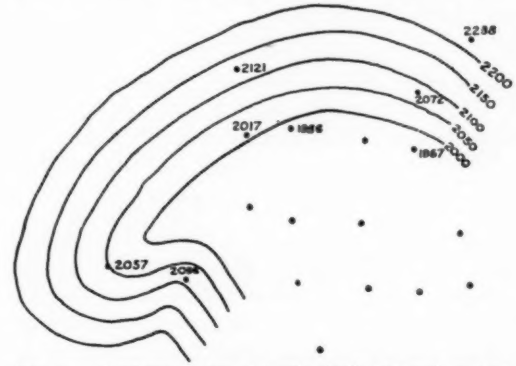

FIG. 13.—Contours on top of Austin chalk. Interval, 50 feet.

was extruded and deposited under submarine conditions. 6. The shape of the dome-like mass as estimated from cross sections and contours is favorable to a submarine extrusion (Figs. 3, 4, 5, 12 and 13). In at least six wells the chalk is reached beneath the volcanic material, the latter showing a marginal thinning suggesting a mushroom-like mass similar to a submarine extrusion flow.

It seems reasonable, therefore, to say that this volcanic material was a submarine extrusion. Successive eruptions of fragmental material and basalt on the sea floor would tend to build up such a dome-like mass. The fragmental character of the rock would naturally result from the sudden aqueous chilling of the lava. The high glassy content, porosity, and the stratified character are due respectively to explosive action of gases, granulation and disintegration on sudden chilling, and to subsequent deposition by the Austin sea. Furthermore, during the submarine eruption sediment would be disturbed, some of which would probably be incorporated in the volcanic material.

Richard E. Fuller[8] has described an occurrence which shows undoubted evidence of aqueous chilling. In comparing the phenomena he describes with those at Hilbig, there is a striking similarity. He writes: "The glass as a rule is largely altered to palagonite, a yellowish earth-like material."

This corresponds very closely with certain phases of glass already mentioned in connection with the Hilbig rock. Further, he says that these fine breccias have a fine foreset bedding. In explanation, he states:

> A fluid lava, on encountering a local body of water, would tend to granulate like molten slag and form a fine breccia . . . the fine breccia would settle until its surface attained a steep angle of repose which, owing to the roughness of the fragments, would be relatively steep.

Applying these findings to our submarine extrusion, the result would be similar. The intensity would probably be greater; the volcanic material on contact with the large body of water would react vigorously and disintegrate lava into fragments which would accumulate around the vent, building up a cone-like mass.

CONTACT METAMORPHISM

Contact specimens showing the contact between the igneous rock and surrounding sediments fail to show more than incipient metamorphism, extremely local and limited in character. The simple induration of some samples of chalk can easily be of original variation in the sediment. For example, a portion of the core from Wolfenbarger No. 1 between 2,765 and 2,785 feet shows a part of the 20-foot interval to be indurated chalk, whiter and harder than other samples from the same interval; the latter appears more similar to the bulk of the normal Austin chalk. This well, drilled in the northeast part of the field, has entirely missed the volcanic body. If metamorphism

[8] R. E. Fuller, "The Aqueous Chilling of Lava on the Columbia River Plateau," *Amer. Jour. Sci.* (April, 1931), p. 281.

had extended to this distance, it probably would have altered more than a small portion of the 20-foot interval, although there is a possibility that this narrow band of chalk might have been more susceptible to alteration than the surrounding chalk. Nevertheless, it would be possible for this localized induration to be due to factors totally unrelated to contact metamorphism.

Contact samples, for example, one from Osborn No. 1, between 2,632 and 2,652 feet, on the north edge of the field, show little change in the chalk, even where directly in contact with and below the volcanic body. The contact shown in this place is a perfectly normal contact of an extrusion with the country rock.

All the material the writers have been able to secure which ever so faintly records any change which might be construed as contact metamorphism occurs *below* the mass, and hence, even if interpreted as metamorphosed, it is still perfectly normal for the suggested origin.

There is no metamorphism of the Taylor, even where directly above the volcanic.

EFFECT OF NATURE OF ROCK ON PRODUCTION

In rock such as that at Hilbig, oil accumulation is, of course, influenced by the original porosity, modified by later infiltration of calcareous material; not by structure of a secondary or tectonic nature, as is commonly the case with accumulation. The dome-like shape of the rock may contribute to centralization of accumulation by virtue of its shape, but this could not be interpreted in the usual meaning of the term structure where the latter is controlling petroleum accumulation.

POROSITY IN THE MASS

The variable porosity in the Hilbig body seems to have a direct relation to its juxtaposition with the Austin chalk above. Lonsdale,[9] in reviewing the occurrence of calcite as matrix and vein material in similar masses, recognizes both original incorporation from a limestone-forming sea and infiltration after or during cooling and lithification. He calls particular attention to its occurrence in the upper parts of bodies where it has clearly been deposited from solution.

In Friske No. 2, Hasler No. 3, and Wilhelm Nos. 3 and 5 (Fig. 2) the wells encounter non-porous rock in the upper part of the body, but porous rock deeper, corroborating Lonsdale's statement for other fields. However, another fact of significance in production is re-

[9] J. T. Lonsdale, *op. cit.*, p. 132.

vealed at Hilbig. Wells which are drilled to the volcanic rock where it is overlain by the overlapping Austin, show low or insignificant production, with one exception which is barely within the overlapping area of chalk. Downward infiltration of calcareous material from the Austin has so affected porosity that it is the rule for such wells to be dry.

The production at Hilbig shows a rough zoning of the porosity as yet wholly unexplained, and for which there appears to be no adequate explanation within the evidence at hand.

SUMMARY

From the evidence at hand, the writers have come to the conclusion that the Hilbig dome represents a submarine volcanic extrusion which was active in late Austin time. The character of the altered rock as compared with that of other fields, the presence of chalk and micro-fossils in the fragmental rock, and the lack of metamorphism in the country rock above the altered body have all contributed to this conclusion.

Although there are some differences, the Hilbig field is favorably comparable with similar producing fields of the Balcones fault area. This similarity is evident in the altered rock, in the general shape of the dome, and in the age. Nearly all of these domes of altered rock are found in the late Austin and/or early Taylor.

The prospect for similar new fields is encouraging, as there seems to have been considerable contemporaneous igneous activity which has already given rise to a number of fields in the Balcones area.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 221-281, 7 FIGS.

OUTLINE OF STRUCTURAL DEVELOPMENT OF TRANS-PECOS TEXAS[1]

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Washington, D. C.

ABSTRACT

The mountain area of trans-Pecos Texas is divisible into a northern part, which has been more or less stable, and a southern part, which has shown considerable mobility from Paleozoic down to Cenozoic time. Strong folds and overthrusts of late Pennsylvanian age, raised from a geosyncline, are found in the Marathon and Solitario uplifts in the southern part of the province. Northwest of them, in the stable area, Permian rocks later than the deformation lie unconformably on broadly folded older Paleozoic foreland rocks, and were deposited in broad basins.

In some mountain ranges of western trans-Pecos Texas, and extending southward into Mexico, are close folds and overthrusts raised from a Mesozoic geosynclinal area. East of them are broad folds, domes, and basins of marginal type. These structural features were produced during two movements, one older and the other younger than the extensive Tertiary lavas of central trans-Pecos Texas. These may be classed as the northern ends of the Sierra Madre Oriental of Mexico. After the last folding, trans-Pecos Texas was extensively broken by normal faults, some of the movements being of late Tertiary age, and some of relatively recent date. In the northern stable part of the province, features of Basin and Range type were produced. Here, thick intermontane deposits were laid down in the areas depressed by faulting. The present surface features of trans-Pecos Texas result in part directly from the various later tectonic movements, and to a greater degree from the modification of the structural features by stream erosion.

INTRODUCTION

For a number of years, during the course of other work, the writer has collected information on the structural features of trans-Pecos Texas. Other duties prevent the writing of a long paper on the subject, but some of the interpretations seem to be of sufficient interest to warrant publication. This paper is a brief outline of the subject, in which most of the discussion consists of suggestions rather than well ordered conclusions.

The writer has done considerable field work in parts of trans-Pecos Texas, especially in the Marathon region in the southeast and the Diablo Plateau on the northwest. Notes and maps of N. H. Darton for other parts of trans-Pecos Texas were also available. Darton's observations were made during the preparation of the new

[1] Manuscript received, September 1, 1934. Outgrowth of papers presented by title before the Association at the Oklahoma City meeting, March 24, 1932, and the Houston meeting, March 24, 1933. Published by permission of the director, United States Geological Survey.

[2] United States Geological Survey.

geologic map of Texas. Maps sent in by other geologists for use in compiling the map were also consulted, particularly an interesting set of field sheets made by C. L. Baker in southwestern trans-Pecos Texas.

ACKNOWLEDGMENTS

Through the kindness of E. H. Sellards and C. L. Baker, the writer has been permitted to read their unpublished manuscript on the geologic structure of Texas, soon to be published as Bulletin 3401 of the Bureau of Economic Geology, University of Texas. The writer has avoided as far as possible duplicating any part of this work, and particularly the extensive descriptive matter which it contains. In places Baker's interpretations on trans-Pecos Texas in this manuscript coincide with, and have to a certain extent influenced those of the writer.

The writer is also indebted to W. S. Adkins, formerly of the Bureau of Economic Geology, for many interesting discussions on the Cretaceous strata of the region, and has made extensive use of Adkin's recent valuable summary of the Mesozoic of Texas.[3] Finally, the writer wishes to acknowledge the receipt of numerous suggestions, and of much useful information on adjacent parts of Mexico, from his brother, Robert E. King.

RELATION OF GEOGRAPHIC TO STRUCTURAL FEATURES

In broader topographic features trans-Pecos Texas consists of two parts. On the west side of Pecos River is a belt of plains and low plateaus 50–100 miles in width. Beyond that is a region of mountains and intermontane basins. The mountains rise above the plains on the east along an irregular boundary, trending approximately northwestward, and the eastern mountains might empirically be considered as a front range. Actually, a true front range of continuous structural and topographic character does not exist, for the origin of the land forms and the underlying rock structure in different places is most diverse.

The northern part of trans-Pecos Texas, north of the Texas and Pacific Railway, is a part of the Basin and Range province. The mountains here are broad blocks of flat-lying or gently tilted Paleozoic rocks which rest on a pre-Cambrian basement. Their outlines are largely determined by faults which bound their bases, and the intermontane areas are deeply filled by detritus washed down from the adjacent highlands (Fig. 5).

[3] W. S. Adkins, "Mesozoic Systems," in "The Geology of Texas," Vol. I, "Stratigraphy," *Univ. Texas Bull. 3232*, (1933), pp. 239–517.

South of the Texas and Pacific Railway, normal faulting has a conspicuous effect on the topography in only a few areas. The region has been one of greater mobility than that farther north, and the sedimentary and volcanic rocks which form the mountains have been tilted, flexed, and in places strongly folded by post-Mesozoic movements older than the last faulting (Fig. 5). In many places there are masses of intrusive igneous rock. The rocks of this region, of diverse composition and structure, possess a varied resistance to erosion, and impart distinctive features to the different mountain masses and lowland areas. The topography in most of the district is thus not produced directly by the uplift or depression of blocks of the earth's crust. The southern part of trans-Pecos Texas, in which these features are displayed, is most closely allied to the mountains and highlands of northeastern Mexico, such as the Sierra Madre Oriental, and it forms their northern end (Fig. 6).[4]

PRE-CAMBRIAN STRUCTURAL FEATURES

Depth of pre-Cambrian floor.—Pre-Cambrian rocks are not widely exposed in trans-Pecos Texas. The most extensive outcrops are along the edges of the uplifted blocks of the Basin and Range province where the sedimentary cover is thin. The largest area of outcrop here is at the margin of the southeastern angle of the Diablo Plateau (Fig. 2) near Van Horn; this is the highest point structurally in trans-Pecos Texas.[5] Its present height is caused largely by block-faulting, but west of Van Horn, Permian rocks overlap the older Paleozoic and rest on the pre-Cambrian over a wide area, and in one part of the district (near Eagle Flat station), the Permian is in turn overlapped by the Cretaceous. The area has, therefore, had a long positive history. Farther east, near Fort Stockton, pre-Cambrian granites have been penetrated by a boring at a depth of 4,750 feet;[6] here they are overlain by the Permian, and probably lie on the crest of a similar positive area of basement rocks (Fig. 2).

[4] The relation between the physical features of trans-Pecos Texas and those of immediately adjacent parts of northern Mexico is shown on Sheet North H-13 (Chihuahua) of the American Geographical Society's millionth map of Hispanic America, published in 1934.

[5] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), p. 41. In this and some other writings Baker refers to the district as the "Van Horn dome." To the writer the term "dome" does not well express the complexity of the uplift: some of the older movements have been domelike, but its present altitude has been produced largely by normal faulting.

[6] E. H. Sellards, "Pre-Paleozoic and Paleozoic Systems," in "The Geology of Texas," Vol. I, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), p. 52.

Southeast of Van Horn, in a belt extending through Marathon, the pre-Cambrian rocks probably lie far below the surface, for this was a region of geosynclinal deposition during Paleozoic time. Southwest of Van Horn also, the pre-Cambrian is probably deeply covered, for a great thickness of Mesozoic sediments was laid down there. Southeast of the Paleozoic geosyncline, the pre-Cambrian floor apparently rises again; schists probably of this age have been found by Baker near the axis of the Sierra del Carmen on the Mexican side of the Rio Grande, 80 miles south of Marathon (Fig. 2).[7] These may lie not far beneath the Cretaceous in a wide area in this part of Coahuila.

Pre-Cambrian structural features in Diablo Plateau.—The character of the pre-Cambrian basement may best be observed near Van Horn. In the southern part of the area the country rock is schist, which strikes predominantly northeast,[8] but locally with northwest, east-west, and even north-south strikes.[9] In the northern part, the country rocks are the little metamorphosed, later pre-Cambrian sediments of the Millican formation (Fig. 1).

Richardson, during his work in the area for the Van Horn folio,[10] did not find the two units in contact, but a few years ago, in the course of field work a little farther west, north of the Texas and Pacific Railway between Allamore and Eagle Flat stations, the writer was able to demonstrate that the contact was one of overthrust (Fig. 1),[11] in which the schists on the south had moved northward across the Millican. The fault trace is exposed at various scattered localities and trends west-northwest; the plane dips about 30° S. and is intruded by diabase sills. In places the faulted rocks are overlain by Permian rocks which are not disturbed. Recently the writer discovered some small outlying masses of schistose rocks resting on limestones of the

[7] Emil Böse, "Vestiges of an Ancient Continent in Northeast Mexico," *Amer Jour. Sci.*, 5th Ser., Vol. 6 (1923), p. 133.
C. L. Baker, "Desert Range Tectonics of Trans-Pecos Texas," *Pan-Amer. Geol.*, Vol. 50, (1928), p. 358.

[8] G. B. Richardson, *U. S. Geol. Survey, Van Horn Folio 194* (1914), p. 7.

[9] C. L. Baker, *op. cit.*, pp. 7–8.

[10] G. B. Richardson, *op. cit.*, p. 4.

[11] The writer's interpretation is shown in the structure section of figure 25 in N. H. Darton, "Guidebook of the Western United States, Part F, Southern Pacific Lines," *U. S. Geol. Survey Bull. 845* (1933), p. 125. It is interesting to compare this with the descriptions and structure section of W. H. von Streeruwitz, "Report on the Geology and Mineral Resources of Trans-Pecos Texas," *Texas Geol. Survey 2nd Ann. Rept.* (1891), p. 682 and section *OP*, Pl. 26, which, excepting the age assignments of some of the rocks, is remarkably accurate.

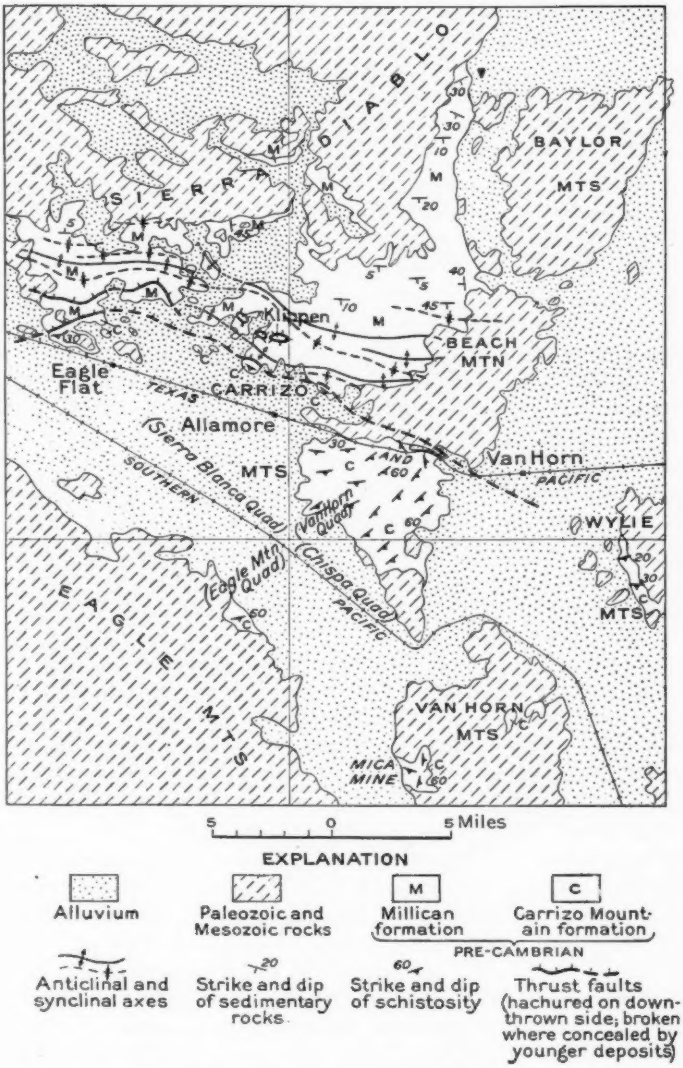

Fig. 1.—Map of Van Horn region to show pre-Cambrian structural features. Area south of Texas and Pacific Railway mainly after G. B. Richardson and C. L. Baker. Area on north by P. B. King.

Millican formation about 4 miles due north of Allamore (Fig. 1). They are probably *klippen* of the overthrust.

North of the fault the limestones of the Millican are sheared and marmorized. For a distance of 3 or 4 miles they and the associated conglomerates and red sandstones are intensely folded with west-northwest strike, but beyond, the metamorphism is no greater than in the overlying Paleozoic, and the formation passes beneath the younger rocks of the Sierra Diablo to the north with dips of only a few degrees.[12] The coarse angular conglomerates of the Millican formation in this region consist in small part of fragments of schist and igneous rock, but predominantly of limestone, presumably derived from a lower member of the formation. Another limestone member is also present at the top of the succession at such places as Tumbledown Mountain west of Beach Mountain (Fig. 1). The conglomerate apparently thins and intergrades with sandstone toward the north, as though derived from an area of uplift near the site of the observed overthrust. The northward thrusting of pre-Cambrian rocks toward a seemingly stable area in the plateau is similar to the structural relations in post-Cretaceous time described later in the paper. Both the schists and unaltered sedimentary rocks are penetrated by numerous small masses of diabase of pre-Cambrian age. The Van Horn sandstone (Cambrian) rests unconformably on them in places, and contains their reworked fragments.

Farther northwest, in the Diablo Plateau, the pre-Cambrian basement apparently consists largely of red granite and rhyolite porphyry. At the base of the Sierra Diablo escarpment northwest of Van Horn the Cambrian (Van Horn sandstone) is a great mass of red arkose with numerous layers of coarse bouldery conglomerate. Surprisingly enough, few of the fragments come from the underlying schistose and sedimentary rocks, but are instead largely of granite and rhyolite. Some of the rounded boulders reach 3 feet across. These coarse clastics must have come from high lands farther northwest, now largely buried by Paleozoic strata. About 35 miles north of Sierra Blanca, within the plateau, are some low hills of rhyolite porphyry like that in the Cambrian conglomerates on the south (Fig. 2); near by are exposures of Permian and Cretaceous limestones. N. H. Darton has suggested to the writer that these are a projecting summit of the pre-Cambrian floor.[13] Farther west, at the south end of

[12] N. H. Darton, *op. cit.*, Fig. 25, p. 125.

[13] N. H. Darton, personal communication, 1930.

the Hueco Mountains, red granite lies unconformably below the Cambrian (Bliss sandstone).[14] These igneous rocks may be younger than the Millican formation, for in the Franklin Mountains west of the Huecos, the Llanoria quartzite is overlain by thick rhyolite flows, and

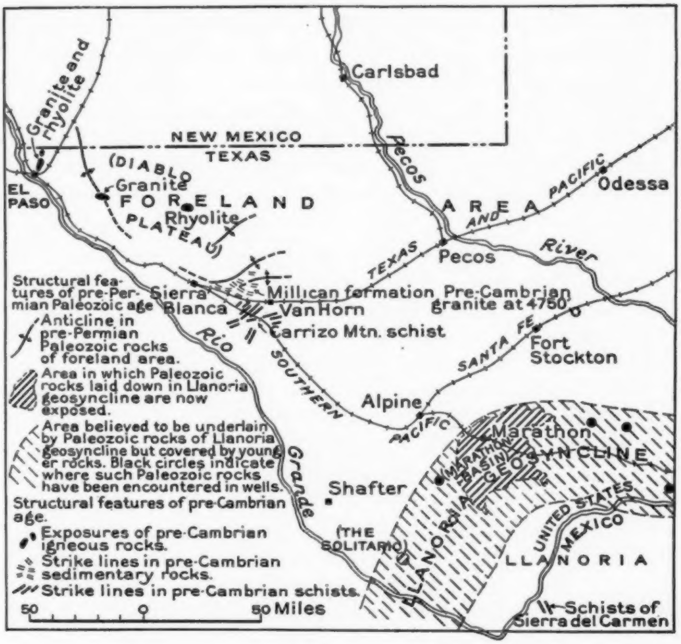

FIG. 2.—Map of trans-Pecos Texas to show pre-Cambrian and pre-Permian Paleozoic structural features.

both in turn are intruded by red granites.[15] This quartzite, like the Millican formation, consists of little metamorphosed or folded rocks, probably of late pre-Cambrian age.

[14] P. B. King, "Permian Stratigraphy of Trans-Pecos Texas," *Bull. Geol. Soc. Amer.*, Vol. 45 (1934), Fig. 2 D, p. 714.

[15] G. B. Richardson, *U. S. Geol. Survey El Paso Folio 166* (1909), p. 6. The rhyolites here were correctly interpreted by Richardson, but all the granites were mapped by him as post-Carboniferous. According to J. G. Barry of El Paso, they are of this age in the northern part of the range only. In the southern part, the writer was, in 1933, shown exposures by Barry in which the Cambrian (Bliss) lay on an eroded surface of red granite.

STRUCTURAL FEATURES OF PRE-PERMIAN PALEOZOIC AGE

Marathon region.[16]—In the Marathon basin of southeastern trans-Pecos Texas (Fig. 2), strongly deformed Paleozoic rocks reaching a thickness of 15,000 feet are exposed. These consist of shaly limestone, bedded chert, and novaculite of Ordovician and Devonian (?) age below[17] and of a vast succession of shales and arkosic sandstone of Pennsylvanian age above.[18] The upper few thousand feet of the Pennsylvanian is more coarsely clastic than the lower part, and includes the remarkable boulder bed of the Haymond formation,[19] whose fragments reach gigantic proportions, and numerous limestone and chert cobble beds in the Gaptank formation above.

These rocks are thrown into northeast-trending folds, overturned toward the northwest, broken by numerous thrust faults, and fractured transversely by many tear faults. The faulting culminates on the northwest in the nearly flat-lying Dugout Creek overthrust, with a known displacement of over 6 miles.[20] Farther southeast are other great thrusts, also with miles of displacement, some of which are folded and therefore younger than that on Dugout Creek. Careful estimates of the amount of crustal shortening in the area suggest that each present mile across the strike of the folds was originally 1½–3 miles wide; moreover, the total displacement of all the overthrusts which would be encountered in a single cross section across the strike would amount to nearly 15 miles.

It is the writer's belief that the movements which produced this great compression were pulsatory. Evidently they culminated toward the end of the Pennsylvanian, for the rocks on the northwest, with *Schwagerina* and other early Permian fossils, are gently tilted rather than folded, and in places overlie the older rocks with great unconformity. The folding began earlier, for lower down in the section, in the Gaptank and Haymond formations, are conglomerates and boulder beds. These contain fragments of rocks of the geosyncline that would have been deeply buried if there had been no movements to

[16] The stratigraphy and structure of this region are described in more detail in a manuscript dealing with the geology of the Monument Spring and Marathon quadrangles, which the writer has submitted to the United States Geological Survey for publication.

[17] P. B. King, "Pre-Carboniferous Stratigraphy of the Marathon Uplift, West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 1059–86.

[18] P. B. King, "Geology of the Glass Mountains," Part 1, "Descriptive Geology," *Univ. Texas Bull. 3038* (1931), pp. 31–49.

[19] C. L. Baker, "Erratics and Arkoses in the Middle Pennsylvanian Haymond Formation of the Marathon area," *Jour. Geol.*, Vol. 40 (1932), pp. 581–92.

[20] P. B. King, *op. cit.*, pp. 108–10.

bring them to the surface. In the Haymond, fragments of the cherty rocks are crumpled and brecciated. The writer has seen such deformation in the cherts in their parent ledges only near faults and close folds.

In brief, then, the structural history of the Marathon basin in Paleozoic time was: first, during the early Paleozoic a great thickness of limy, cherty, and fine clastic sediments accumulated in an area of subsidence, the Llanoria geosyncline.[21] Next, in early Pennsylvanian time the sediments became coarser, probably as a result of strong uplift of lands on the southeast; the sediments filled the geosyncline more rapidly than before, since they exceed in thickness the underlying deposits. The fine fragments are, however, of granitic and metamorphic rocks which are foreign to the region. Then, in later Pennsylvanian time, conditions radically changed and coarse conglomerates appear which have a near-by source. The presumption is strong that they were derived from folds rising from the geosyncline. Finally, near the end of Pennsylvanian time, the whole folded mass was driven forward on the Dugout Creek overthrust. This fault has not since been folded and Permian rocks overlie it unconformably, so that these late Pennsylvanian events probably mark the last phase of the intense deformation.

Extensions of Marathon folds southwest and northeast.—The Llanoria geosyncline did not have the same form as the modern, nearly circular Marathon basin, but had a much greater extent toward the southwest and northeast (Fig. 2). At the edges of the Marathon basin, rocks of geosynclinal facies strike in these directions beneath the Cretaceous cover. On the southwest a small patch of the folded rocks comes up in the Solitario dome, 35 miles southwest of the edge of the basin (Fig. 2).[22] Here Sellards reports the existence of folded overthrusts like those southeast of the Dugout Creek thrust in the Marathon basin. The further extension of the folds toward the southwest is not known, since in this direction they pass beneath a thick cover of Cretaceous strata and Tertiary lava flows.

A few miles east of the Marathon basin, water wells several hundred feet deep penetrate Pennsylvanian rocks of Marathon facies,[23] and deep wells in the southeast part of Terrell County and in Val

[21] E. H. Sellards, *op. cit.*, p. 129.

[22] *Ibid.*, Fig. 9, p. 119.
"Overthrusting in the Solitario Region" (abstract), *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), pp. 145–46.

[23] D. D. Christner and O. C. Wheeler, "The Geology of Terrell County," *Univ. Texas Bull. 1819* (1918), pp. 11–12.

Verde County have entered sheared and talcose (and therefore probably deformed) shales, possibly of Pennsylvanian age, after passing through a thick Cretaceous section.[24] The position of these wells suggests that the strike of the folded belt bends to an east-southeast course east of the Marathon basin (Fig. 2), but farther east, according to the work of Sellards, Miser,[25] and others, it again bends toward the north and emerges from the Cretaceous cover in the Ouachita Mountains of Oklahoma.

Paleozoic land area of Llanoria.—On the southeast, the Llanoria geosyncline was probably bounded by an area of highlands underlain by crystalline rocks. This has been called Llanoria by analogy with the land mass of that name which is supposed to have lain south of the Ouachita Mountains.[26] The existence of such a land is suggested in the Paleozoic sediments in the Marathon basin by the thickening of clastic and cherty sediments southeastward; by the replacement of limestones by shales, and of shales by sandstones in this direction; and by the occurrence in the clastic sediments of pebbles of vein quartz, grains of schistose and granitic rocks, and (in the Haymond boulder bed) of cobbles of igneous rocks.

A positive area which existed in northeastern Mexico in early Mesozoic time may have been a remnant of the older land, Llanoria[27] (Fig. 7). In this region, which occupied part of northern Coahuila, Jurassic and early Cretaceous rocks are either absent or are represented by a marginal clastic facies.[28] Within the area, in the Sierra del Carmen, the schists reported by Baker are overlain by Lower Cretaceous rocks approximately of Glen Rose age, and at Las Delicias, Coahuila (Fig. 7), rocks of the same age rest directly on the Permian.[29] South and southwest of a line extending westward from Saltillo to

[24] E. H. Sellards, "Pre-Paleozoic and Paleozoic Systems," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), pp. 190–91 and Fig. 10, p. 128.

[25] H. D. Miser and E. H. Sellards, "Pre-Cretaceous Rocks Found in Wells in the Gulf Coastal Plain South of the Ouachita Mountains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 7 (July, 1931), pp. 807–08.

E. H. Sellards, "Rocks Underlying Cretacous in Balcones Fault Zone of Central Texas," *ibid.*, pp. 819–20.

[26] H. D. Miser, "Llanoria, the Paleozoic Land Area in Louisiana and Eastern Texas," *Amer. Jour. Sci.*, 5th Ser., Vol. 2 (1921), pp. 61–89.

[27] P. B. King, "An Outline of the Structural Geology of the United States," *Guidebook 28 International Geol. Cong. XVI Session, 1933*, p. 41.

[28] Emil Böse, "Vestiges of an Ancient Continent in Northeast Mexico," *Amer. Jour. Sci.*, 5th Ser., Vol. 6 (1923), pp. 130–136.

[29] R. E. King, "The Permian of Southwestern Coahuila," *Amer. Jour. Sci.*, 5th Ser., Vol. 27 (1934), p. 109.

Torreon in southern Coahuila, and thence northwestward through Chihuahua to western trans-Pecos Texas, Jurassic and early Cretaceous rocks are developed to a great thickness. Strong post-Mesozoic folding took place in this area of thick sedimentation and the general northwestward Cordilleran trend is deflected around the positive area.[30]

Foreland areas northwest of Llanoria geosyncline.—The northwest edge of the Llanoria geosyncline may have lain near the northwest margin of the present Marathon basin. In this district, near the front of the Dugout Creek overthrust, the lowest formation of the Pennsylvanian (Tesnus), a typical geosynclinal deposit of sandstones and shales, is only a few hundred feet thick, although a few miles farther southeast it is several thousand feet in thickness.[31] A few miles south of the outcrop of the overthrust, a shale formation in the Ordovician contains large limestone boulders of Cambrian and Ordovician age, of foreland facies.[32] Whether these reached their present positions by normal processes of transportation and deposition, or by some process of tectonic intercalation, they suggest that the foreland area lay not far on the northwest. The Dugout Creek overthrust may form the boundary between geosynclinal and foreland rocks in this part of the basin, but nothing is known of the older rocks overridden by the fault. In the northeast part of the basin, the disturbance in the Paleozoic rocks appears to die out northwestward by diminution of the folds, so that the highest Pennsylvanian passes beneath tilted Permian of not greatly younger age beyond, without evident difference in dip or strike.

Northwest of the Llanoria geosyncline the nearest exposures of the pre-Permian Paleozoic rocks lie at a distance of a hundred miles or more and are of very different facies. As exposed along the edges of the Diablo Plateau and Franklin Mountains in the Basin and Range province, the section is largely limestone. At the base are Upper Cambrian sandstones resting on the pre-Cambrian basement and followed by several thousand feet of Ordovician and Silurian limestones.[33] A number of stages of the Middle Ordovician found at Mara-

[30] Emil Böse, *op. cit.*, Fig. 1, p. 128.
L. B. Kellum, "Reconnaissance Studies in the Sierra de Jimulco," *Bull. Geol. Soc. Amer.*, Vol. 43, (1932) pp. 541–64.

[31] P. B. King, "The Geology of the Glass Mountains," Part I, "Descriptive Geology," *Univ. Texas Bull. 3038*, pp. 31–32.

[32] P. B. King, "Pre-Carboniferous Stratigraphy of the Marathon Uplift," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 9 (September, 1931), pp. 1063–64.

[33] G. B. Richardson, *U. S. Geol. Survey El Paso Folio 166*, pp. 3–4; *U. S. Geol. Survey Van Horn Folio 194*, pp. 4–5.

thon are absent here, although the Silurian has no representative at Marathon. The Mississippian and Pennsylvanian together are but 2,000 feet thick and nearly all limestone. Beds at Marathon equivalent to part of the section are clastic. The highest Pennsylvanian beds of the Hueco Mountains are of about the same age as the highest ones at Marathon, but in the Sierra Diablo, no strata higher than the lower Pennsylvanian remain.[34] The Pennsylvanian and older rocks were gently folded and deeply eroded before Permian time, so that the basal Permian strata, containing *Schwagerina*, rest in the northern Hueco Mountains on the Pennsylvanian, in the southern Hueco Mountains on rocks as old as the Ordovician, and in the southern Sierra Diablo on the pre-Cambrian. In the Pennsylvanian section of the Hueco Mountains there is no evidence of movements before the close of the period of deposition, and it is probable that the deformation in this foreland area corresponds with the culmination of the movements at Marathon.

The late Pennsylvanian uplift in the Hueco Mountains follows the general northwest trend of the present range (Fig. 2), with the older rocks dipping more steeply than does the Permian off each side of the axis. In the Sierra Diablo a reconstruction of the late Pennsylvanian folds which are truncated by the Permian indicates that they had a northeast trend (Fig. 2). A particularly well marked broad syncline extends northeastward from the southeast corner of the Sierra Diablo under the Baylor Mountains (Fig. 1). The folds in the Hueco Mountains and the Sierra Diablo apparently follow the west and southeast edges of the Diablo Plateau area.

East of the Sierra Diablo the Paleozoic foreland rocks are deeply covered by younger strata. Near Fort Stockton, as previously noted, pre-Cambrian granites have been penetrated by the drill beneath the Permian. Still farther east, Pennsylvanian limestones and Middle Ordovician shales have been penetrated by deep wells in Reagan County,[35] and beneath them are limestones probably to be correlated with the Ellenburger farther east. The latter has also been reached by deep borings in Crockett and eastern Pecos counties on the south,[36] within 100 miles of the Marathon basin. These rocks, like those in northwestern trans-Pecos Texas, are of foreland facies.

[34] P. B. King, "Permian Stratigraphy of Trans-Pecos Texas," *Bull. Geol. Soc. Amer.*, Vol. 45, pp. 697–798.

[35] E. H. Sellards, H. P. Bybee, and H. A. Hemphill, "Producing Horizons in the Big Lake Oil Field, Reagan County," *Univ. Texas Bull. 3001* (1930), pp. 149–203.

[36] E. H. Sellards, "Pre-Paleozoic and Paleozoic Systems" in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232*, (1933), p. 80.

PERMIAN STRUCTURAL FEATURES

After the late Pennsylvanian deformation the former area of subsidence of the Llanoria geosyncline stood as a land area, probably of mountainous character. North and northwest of this land, Permian sediments were deposited in new areas of subsidence, or foredeeps,[37] formed on the surface of broadly folded and deeply eroded foreland rocks. The subsidence was apparently irregular, and various facies of Permian sediments were sharply limited.

Stratigraphic relations.[38]—In such areas in trans-Pecos Texas as the Glass, Guadalupe, Delaware, and Apache mountains, and the Sierra Diablo, great changes in the character of the Permian strata may be observed along the strike. Thick deposits of siliceous shale are found in the Glass Mountains, and in the north similar rocks are associated with black shaly limestone and fine-grained sandstone. The three types of rock are apparently closely related; the sandstone grades by diminution of the grain size into siliceous shale, and the shale by increase in calcareous and bituminous matter into black limestone. In the Glass Mountains and Shafter district in the south, at least a part of these sediments came from the erosion of the upraised folds of the Llanoria geosyncline, since they contain fragments of granite and of the older Paleozoic cherts and limestones, but the source of the greater part of the Permian clastic sediments is still problematical.

Laterally the clastic sediments interfinger with massive lenticular bodies of limestone which are generally interpreted as limestone reefs.[39] Beyond the limestone reefs are bedded dolomitic limestones. The direction of this change in facies is the same in all parts of each section, but varies from one mountain area to another. These lateral changes are represented in the stratigraphic diagram of the Glass Mountains by the writer, and that of the Guadalupe Mountains by Crandall.[40] There was a tendency for rocks of one facies to be deposited in the same general area throughout Permian time.

[37] W. A. J. M. van der Gracht, "Permo-Carboniferous Orogeny in the South-Central United States," *Verh. der Kon. Akad. van Wetenschappen te Amsterdam*, Deel 27, No. 3 (1931), pp. 80–81.

[38] The stratigraphic and structural features of the Permian of this region are discussed and interpreted at greater length in the writer's paper on, "Permian Stratigraphy of Trans-Pecos Texas," *Bull. Geol. Soc. Amer.*, Vol. 45 (1934), pp. 697–798.

[39] E. R. Lloyd, "Capitan Limestone and Associated Formations of New Mexico and Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 6 (June, 1929), pp. 645–48.

[40] P. B. King, "Geology of the Glass Mountains," Pt. 1, "Descriptive Geology," *Univ. Texas Bull. 3038* (1931), Fig. 17, p. 52.

K. H. Crandall, "Permian Stratigraphy of Southeastern New Mexico and Adjacent Parts of Western Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), Fig. 4, p. 934.

Drilling east of the mountains has disclosed similar relations, and demonstrated that this complex of clastic deposits, limestone reefs, and bedded limestones extends far toward the east. East of Pecos River borings have penetrated a broad uplift of north-northwest trend, not exposed at the surface, known as the Pecos uplift (Central Basin platform).[41] This is capped on the west side by massive

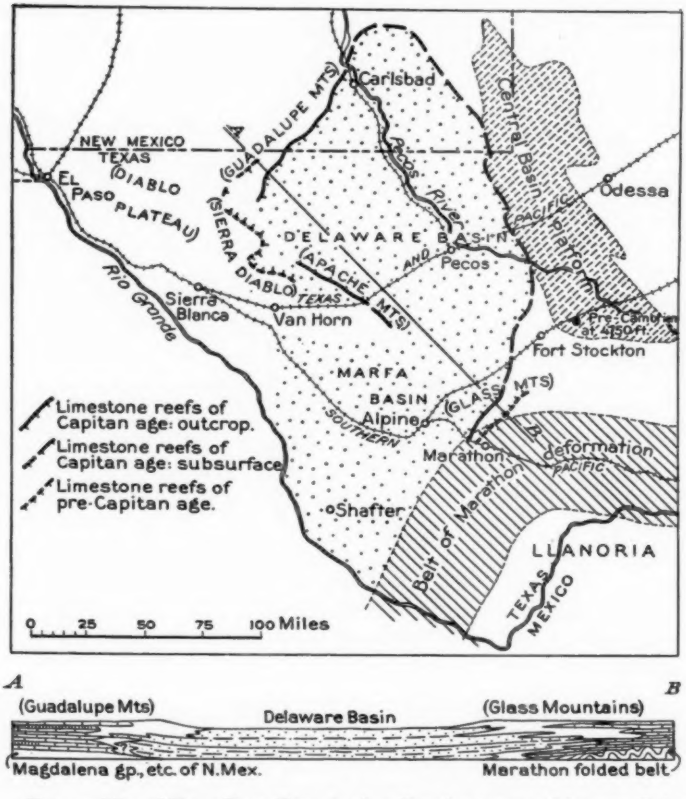

FIG. 3.—Map of Trans-Pecos Texas to show Permian structural features. Below is hypothetical stratigraphic diagram along line *AB* of map. Subsurface information chiefly from Bybee, Cartwright, and Lloyd. Surface information by P. B. King. The Central Basin platform has also been called the Pecos uplift. The Midland basin, noted in the text, lies east of it.

[41] Called Pecos uplift by Sellards, *op. cit.*, p. 52. Originally named the Central Basin platform by L. D. Cartwright, "Transverse Section of Permian Basin, West Texas and Southeast New Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 8 (August, 1931), p. 970.

limestone deposits similar to those in the mountain areas farther west. They are shown by drilling to have been connected, in their later stages at least, with the upper limestones of the Glass Mountains on the south, and those of the Guadalupe Mountains on the north (Fig. 3). The black limestones, siliceous shales, and sandstones were apparently confined in their extent to the area between the limestone reefs in the mountains on the west and those on the Pecos uplift on the east. This intervening area has been called the Delaware basin.[42]

Other similar basins apparently existed on the east and west. East of the Pecos uplift is the Midland basin,[43] known only from drilling, which was joined with the Delaware basin around the south end of the Pecos uplift. West of the Delaware basin, south of the Sierra Diablo, and west of the Glass Mountains, there appears to have been another depression, which has been called the Marfa basin (Fig. 3),[44] but this feature is not well known.

During Permian time there was a gradual retreat of the sea southwestward, so that marine conditions persisted in the Midland basin and the area on the northeast only until the middle of the epoch. After this, the basin was cut off from free access to the sea and received only saline deposits and red sediments. Marine conditions persisted longer in the Delaware basin, but later on (in post-Capitan time) it too was cut off from the sea, and was filled by the gypsum, anhydrite, salt, and potash deposits of the Castile formation.

Structural features.—The Delaware basin, of which most is now known from a study of exposures and drill records, is believed by the writer to have been a region of subsidence greater than that of the surrounding areas during the time of Permian deposition. As such, it served as a trap for the clastic sediments deposited in it. The subsidence was probably greatest in the center where the deposits appear to be the thickest, but all the basin may have subsided more than the surrounding areas, which were apparently more stable. At many places, in exposures along the margins of the basin, the writer has observed that the rocks are bent down toward it on monoclinal flexures, which separate the clastic deposits from the limestone deposits near by.

The outlines of the basin were perhaps determined by lines of

[42] Originally named the Delaware Mountain basin by Robin Willis, "Structural Development and Oil Accumulation in Texas Permian," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), Fig. 1, p. 1034.

[43] So called by Sellards in his unpublished manuscript on the geologic structure of Texas. Originally named the main Permian basin by Willis, *op. cit.*, Fig. 1, p. 1034.

[44] F. H. Lahee, "Contributions of Petroleum Geology to Pure Geology in the Southern Mid-Continent Area," *Bull. Geol. Soc. Amer.*, Vol. 43 (1932), Fig. 2.

weakness in the basement rocks of the region. In the Apache Mountains and the Sierra Diablo, the margins of the basin area trend west-northwest and lie close to and parallel with Tertiary normal faults. The latter may have been produced by later movements along the same lines of weakness. A similar relation can be suspected in the Pecos uplift. Drilling in at least one place, near Fort Stockton toward its southern end, has shown it to be underlain by pre-Cambrian rocks at a relatively shallow depth. On Bybee's map[45] the platform is represented with block-like outlines, composed of a number of straight north-northwest trending parts which stand in *en échelon* relation to each other. The limestone reefs follow, in a general way, the margins of the uplift. Although the reefs are crossed by later minor folds,[46] this parallelism is close enough to suggest that the reefs owe their positions to a structural control. It is possible that slight movements on monoclinal flexures at the time of deposition would bring about an environment, on the upper parts of the flexures, which would be more favorable than the surrounding areas, both for the precipitation of limestone and for the growth of lime-secreting organisms. The Diablo Plateau area, west of the Delaware basin, received limestone deposits during Permian time, and may, like the Pecos uplift, have been a relatively stable area.

The formation of basins and platforms in the foreland area during Permian time was accomplished by relatively slight movements. It may be that toward the southeast, within the area of the former Llanoria geosyncline and the land Llanoria, there were stronger movements. At Las Delicias, southwestern Coahuila, which may lie within this province, the Permian rocks are largely lava flows and tuffs, with subordinate marine shales and limestones. These rocks are thrown into steep folds, broken by small overthrust faults, and intruded by granite.[47] The deformation by which this was accomplished is older than the Cretaceous, but is younger than the strong folding and faulting in the Llanoria geosyncline in trans-Pecos Texas. It may, however, have been a continuation of the same disturbance.

MESOZOIC AND EARLY TERTIARY STRATIGRAPHY

In early Mesozoic time the surface features of late Paleozoic time were obliterated by a long period of erosion, during which the region

[45] H. P. Bybee, "Some Major Structural Features of West Texas," *Univ. Texas Bull. 3101* (1931), Fig. 5, p. 26.

[46] According to information from the subsurface geologists. An example of later folding near a limestone reef is given by Willis, *op. cit.*, Fig. 3, p. 1039.

[47] R. E. King, "The Permian of Southwestern Coahuila," *Amer. Jour. Sci.*, 5th Ser., Vol. 27 (1934), pp. 108–11.

was reduced to a peneplain. There was a slight recurrence of downwarping in the Permian basin northeast of trans-Pecos Texas, where Triassic red beds (Dockum group) were deposited,[48] but activity on Paleozoic structural lines almost ceased. Deposition commenced in Jurassic time in new basins which had a different position and different outlines from those of the Paleozoic.

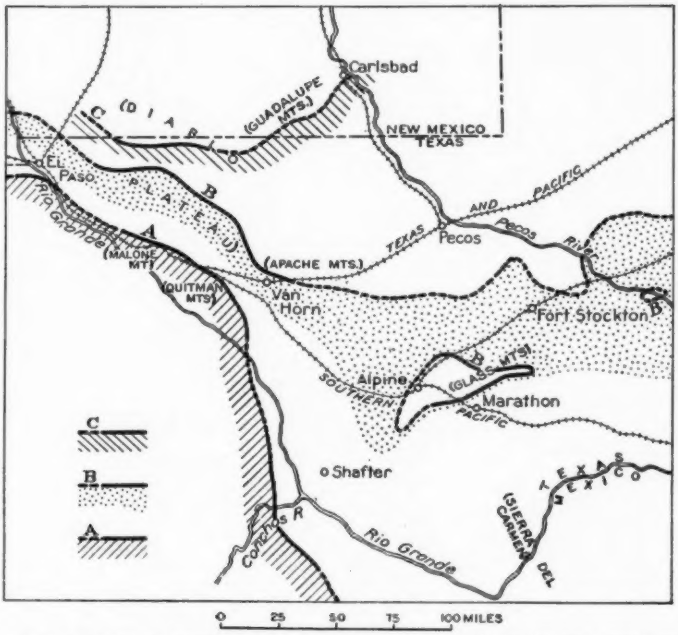

FIG. 4.—Map of trans-Pecos Texas to show advance of sea during Jurassic and Lower Cretaceous time. *A*—Shore line in late Jurassic and early Cretaceous time. *B*—Shore line at close of Trinity time; stippled area show extent of marginal sandstone facies of Trinity group. *C*—Shore line at close of Fredericksburg time. Based on observations of W. S. Adkins, C. L. Baker, and P. B. King.

Jurassic and Lower Cretaceous stratigraphy.—In late Jurassic time, seas extended into a new northwest-trending geosynclinal area lying west and southwest of trans-Pecos Texas (Fig. 4). Northwestward the geosyncline extended as far as the mountains in Mexico south of El Paso and the Eagle, Quitman, and Malone mountains on the Texas side of Rio Grande. Southeastward, it followed the southwest side of the early Mesozoic positive area of northern Coahuila.

[48] J. E. Adams, "Triassic of West Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 8 (August, 1929), pp. 1045–54.

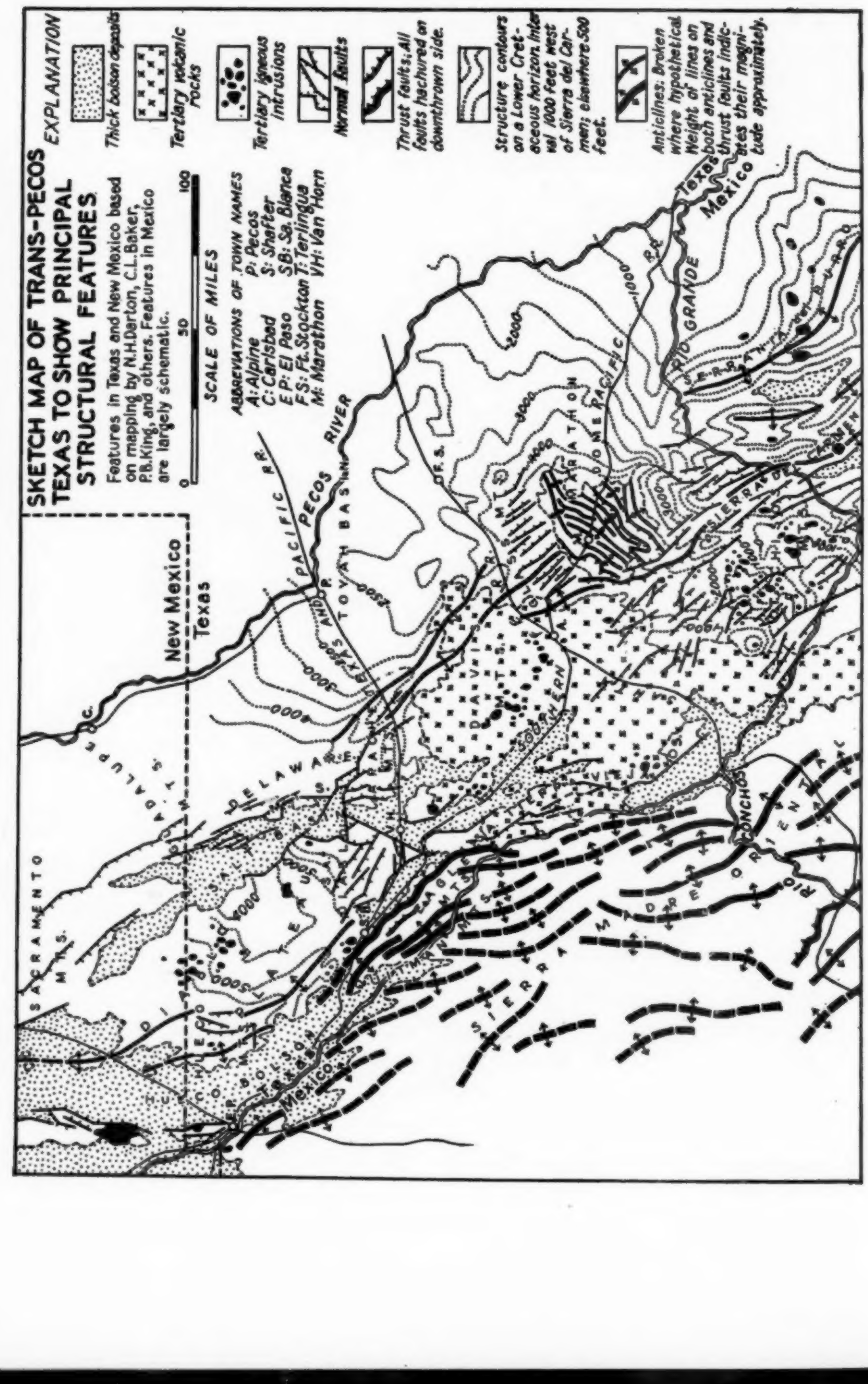

FIG. 5.—Map of trans-Pecos Texas to show principal structural features.

A typical geosynclinal section of Jurassic and Lower Cretaceous rocks is exposed along Conchos River in northeastern Chihuahua, across the Rio Grande from trans-Pecos Texas (Fig. 5).[49] Here, the lower 4,000 feet are shales, thin limestones, and thick sandstones, with locally some gypsum, of late Jurassic and early Cretaceous (Neocomian and Aptian) age. This is followed by 5,000 feet of massive rudistid limestone, embracing the upper part of the Trinity, the Fredericksburg, and the Washita groups of Texas. The same formations are also probably present farther southeast, at Sierra Mojada, Coahuila (Fig. 7).[50] A similar, thinner sequence is found in the Malone and Quitman mountains in Texas.[51]

In the foreland area of trans-Pecos Texas on the east and northeast the deposits thin out.[52] Jurassic and early Cretaceous rocks are unknown outside the geosynclinal area, and successive parts of the later Lower Cretaceous section disappear northeastward by overlap on the Paleozoic (Fig. 4). The thick limestone mass of the Conchos valley thins and loses its identity. In southern trans-Pecos Texas the Washita and Fredericksburg parts retain their massive character and form imposing escarpments and canyon walls several thousand feet in height in the Mesa de Anguilla south of Terlingua, and the Sierra del Carmen on the east (Fig. 6).[53] The Trinity part, however, has changed here to alternating limestones and marls,[54] which northward in the Marathon region thin to a few hundred feet and are replaced by a marginal sandstone facies which forms the basal deposit of the Lower Cretaceous in central trans-Pecos Texas (Fig. 4).[55] The Fredericksburg part of the massive rudistid limestones extends far toward the northeast as the Edwards limestone, but in the central Diablo Plateau, it also changes into a marginal sandstone facies,[56] which almost, if not quite, disappears by overlap near the New Mexico line (Fig. 4).[57] The massive limestones of the Washita group change

[49] From notes furnished by W. S. Adkins and R. E. King after field work in June and July, 1933. See also R. H. Burrows, "Geology of Northern Mexico," *Bol. Soc. Geol. Mexicana*, Vol. 7 (1910), pp. 1–15.

[50] Personal communication from W. S. Adkins, January, 1934.

[51] W. S. Adkins, "Mesozoic Systems," in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), pp. 292–97.

[52] W. S. Adkins, *op. cit.*, Fig. 15, p. 292.

[53] J. A. Udden, "Sketch of the Geology of the Chisos Country," *Univ. Texas Bull. 93* (1907), pp. 23–26.

[54] W. S. Adkins, *op. cit.*, p. 305.

[55] P. B. King, "The Geology of the Glass Mountains," Pt. 1, "Descriptive Geology," *Univ. Texas Bull. 3038* (1931), p. 91.

[56] W. S. Adkins, *op. cit.*, p. 353.

FIG. 5.—Map of trans-Pecos Texas to show principal structural features.

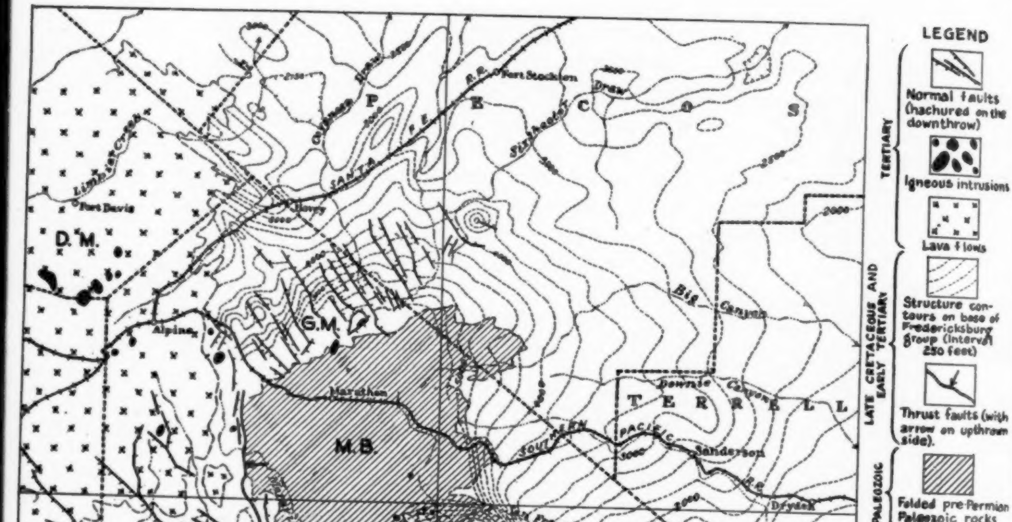

FIG. 6.—Map of southwestern trans-Pecos Texas to show structural features in greater detail than in preceding figure.

northward into marls with abundant fossils of neritic facies; near Fort Stockton two tongues of rudistid limestone of the southern facies are interbedded.[58]

Upper Cretaceous stratigraphy.—The lower part of the Upper Cretaceous, consisting of shales and chalky limestones, is extensively exposed over trans-Pecos Texas, and is found in a few patches overlying the Lower Cretaceous in the geosyncline on the west. The upper part (of Taylor and younger age) is preserved, however, only in two remnant areas, the Sierra Tierra Vieja and the downwarped area surrounding the Chisos Mountains (Figs. 5 and 6). These upper strata, about 3,000 feet thick, record a gradual change from marine to continental conditions.[59] Resting on fossiliferous marine shales of Taylor age are sandstones, containing marine fossils in their lower part and coal beds and dinosaur remains above (Aguja of Adkins). These are followed by bright colored clays (Tornillo of Udden) which are apparently the highest Cretaceous in the region. These are overlain by tuffaceous beds which are apparently of Tertiary age.[60]

Similar beds are found in Mexico on the south, at Hacienda de Mohovano, Coahuila, between Sierra Mojada and Las Delicias (Fig. 7), which contain fossil wood and dinosaur bones, as well as conglomerate beds.[61] No strata of this age have been reported in the geosynclinal area on the west.

Early Tertiary stratigraphy.—Volcanic rocks of Tertiary age occupy a wide tract in central trans-Pecos Texas, including the Davis Mountains on the north, and extending to the Rio Grande between Terlingua and Shafter on the south (Fig. 5). The volcanic succession of lavas, tuffs, and agglomerates reaches a thickness of 4,500 feet in the Sierra Tierra Vieja toward the west.[62] In the Davis Mountains the thickness is less, but even here some escarpments and canyon walls show sections up to 2,000 feet in thickness. Intrusive rocks in the form of dikes, plugs, bosses, and laccoliths, found both in the

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[57] *Ibid.*, pp. 354–55.

[58] *Ibid.*, p. 361, *et seq.*

[59] J. A. Udden, *op. cit.*, pp. 41–67.
W. S. Adkins, *op. cit.*, pp. 505–14.

[60] J. A. Udden (*op. cit.* p. 68) found no evident break in the Chisos country between the Tornillo and the tuffaceous beds (Chisos formation) and concluded that the Cretaceous-Tertiary boundary lay above them. The placing of the boundary in the present paper follows the recent conclusions of C. L. Baker for the Sierra Tierra Vieja and C. P. Ross for the Chisos country.

[61] C. Burckhardt, "Etude synthetique sur le Mesozoique mexicain," *Société Paleontologique Suisse Memoires 49–50* (1930), pp. 217–59.

[62] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), p. 35.

lava country and in surrounding areas of sedimentary rocks, probably belong to the same general epoch. The igneous rocks range from basic to acidic,[63] but alkalic types are common in all classes.

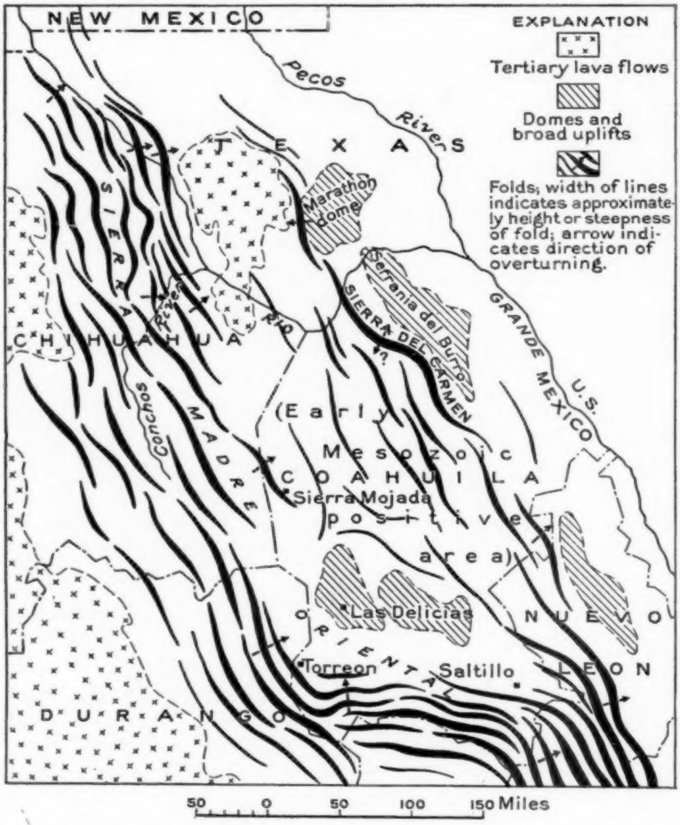

FIG. 7.—Map of western Texas and adjacent parts of northeastern Mexico, to show relation of post-Cretaceous folds of trans-Pecos Texas to those of Sierra Madre Oriental. Compiled from various published and unpublished sources, including Böse, Kellum, and R. E. King.

In the Chisos country the volcanic succession (Chisos formation of Udden) begins with white clays and tuffaceous sandstones, which rest with abrupt contact on the latest Cretaceous clays below. These

[63] F. B. Plummer, "Cenozoic systems," in "The Geology of Texas," Vol. I, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), pp. 800–03.

are followed by coarser sediments, largely of pyroclastic origin, containing numerous lenses of conglomerate, whose fragments are well-rounded pebbles and cobbles of igneous rock and of Lower Cretaceous limestones and cherts. These are overlain by lava flows with interbedded agglomerates and tuffs.[64] A similar succession of pyroclastic sediments (Vieja formation of Vaughan), with few lava flows in the lower several thousand feet, has been studied by Baker in the Sierra Tierra Vieja, but at this place it rests with slight angular discordance on the latest Cretaceous beds below. At the base are conglomerates which contain "huge boulders of Permian and of Lower Cretaceous rocks."[65] It is possible that Tertiary sedimentation began earliest in these two areas, and that the younger members of the volcanic succession overlapped the higher surrounding areas which had been more highly elevated and folded after Cretaceous time.

In areas outside the Chisos country and the Sierra Tierra Vieja the Tertiary volcanic rocks rest, not on the highest Cretaceous, but on a considerable variety of older rocks. At numerous places they lie on the lower part of the Upper Cretaceous (Eagle Ford and Austin), and at many others on the Lower Cretaceous. The steeply tilted Cretaceous rocks on the west flank of the Solitario dome are overlain by lavas gently tilted in the same direction. At one place on the north flank these overlap onto the lower beds of the Washita group, and in the basin carved from the crest of the dome, pyroclastic rocks rest on the folded Paleozoic.[66] A short distance to the west, in the dome-like uplift of the Shafter district, lavas and tuffs lie on the truncated surface of Lower Cretaceous and Permian rocks.[67] Outlying patches of the volcanics rest with gentle dips on the strongly folded and faulted geosynclinal rocks of the northern Eagle and southern Quitman mountains. Similar small patches are reported by R. E. King near Conchos River in Chihuahua. Here they have been tilted, but not as steeply as are the Cretaceous rocks.

In the southeastern Davis Mountains, Baker has collected plants from tuffs near the base of the volcanics, to which an Eocene age has been assigned.[68] Farther north, and also near the base of the vol-

[64] J. A. Udden, *op. cit.*, pp. 60–66, also personal communications from C. P. Ross, August, 1934.

[65] Letter from C. L. Baker, June, 1931.

[66] As pointed out to the writer in the field by C. P. Ross, August, 1934.

[67] C. L. Baker, "Note on the Permian Chinati Series," *Univ. Texas Bull. 2901* (1929), p. 81.

[68] C. L. Baker and W. F. Bowman, "Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas," *Univ. Texas Bull. 1753* (1917), p. 123.

canics, mammalian teeth have been collected by him which are said to be of Oligocene age.[69] In the western part of the area, Baker has seen only the remains of land tortoises in the volcanics.[70] At the present time no fossils of Miocene age have been collected in the succession. That its upper part may be of this age is suggested by the widespread occurrence of Miocene tuffs and lavas in northern New Mexico and elsewhere in the Cordilleran province. The plant and vertebrate fossils in the lower part of the succession furnish conflicting evidence for its age, but they seem definitely to be older than Miocene.

EARLY TERTIARY STRUCTURAL FEATURES

Most of the folding and faulting of the rocks of southern trans-Pecos Texas occurred in the first half of the Tertiary period, and is the northern continuation of structural features in the Sierra Madre Oriental of northeastern Mexico. In Mexico, south of Saltillo, Coahuila, the Sierra Madre is a single bundle of close folds of north-northwest trend, which face the Gulf Coastal Plain on the east. In the vicinity of Saltillo the Sierra Madre bifurcates northward (Fig. 7). The lower outer folds, composed largely of Lower and Upper Cretaceous rocks, continue north-northwestward through Coahuila into eastern trans-Pecos Texas. The main group of folds bends west. following the belt of Jurassic deposition which lies south of the early Mesozoic positive area and then, near Torreon, turns north-northwestward and extends through Chihuahua into the Quitman, Eagle, and Malone mountains of trans-Pecos Texas (Fig. 7).

Western branch of Sierra Madre.—The western group of folds was raised from the thick deposits of the Jurassic and Lower Cretaceous geosyncline, as may be seen by comparing Figures 4 and 5. Both along Conchos River in Chihuahua, and in the Quitman and Eagle mountains in Texas, the geosynclinal rocks are thrown into long steep folds, trending north-northwest, and are broken by overthrust faults which in Texas have carried these rocks northeastward over the thinner foreland sequence of the Lower Cretaceous.[71] Remnant patches of Tertiary lavas rest on the truncated edges of the folds in the northern Eagle and southern Quitman mountains. There appears, however, to have been some broad arching after the lavas were deposited. Thus, they dip northeast and southwest off the axis of the Quitman Mountains. They are also found low in the intermontane area east of the

[69] F. B. Plummer, *op. cit.*, p. 805.

[70] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), p. 35.

[71] *Op. Cit.*,"Overthrusting in Trans-Pecos Texas," *Pan-Amer. Geol.*, Vol. 53 (1929), p. 24.

Eagle Mountains, whereas in that range and in the next one at the east, they cap the summits. In this range on the east, Baker has found some thrust faults which displace the volcanics.[72] In the Conchos River area of Chihuahua, R. E. King has observed down-warped patches of Tertiary lava between the anticlinal areas of Mesozoic rocks. These rest unconformably on more steeply downfolded Upper Cretaceous strata.

Toward the northwest, near the Texas and Pacific Railway, the intense folding of the western branch of the Sierra Madre dies out along the strike. North of the railway are the gently tilted and block-faulted rocks of the Diablo Plateau and other mountain areas of the Basin and Range province. In the western part of the plateau a line of broad arches extends northwestward from the Quitman Mountains into New Mexico (Fig. 5), closely following the fold of Paleozoic age in the Hueco Mountains (Fig. 2). It is probably an outer branch of the system of close folding.

Eastern folds of Sierra Madre.—The eastern branch of the Sierra Madre enters Texas as the high broad fold of the Sierra del Carmen (Fig. 6) which dies out south of the Marathon region. It is broken by normal faults, and Baker reports[73] that in the Mexican part of the range there are one or two great faults on the west side. Two other broad folds west of the Sierra del Carmen in Mexico, the Sierra San Vincente, and Mariscal Mountain, reach up to the Rio Grande or pass beyond it only a few miles before they die out (Fig. 6).[74] North of the Sierra del Carmen is the much smaller and narrower anticline of the Santiago and Del Norte mountains, which in their northern part form the crumpled western edge of the Marathon dome. This fold, like the Sierra del Carmen, is faulted on the western side. The fault is a thrust fault which has carried strata westward,[75] in a direction the reverse of the thrusting farther west. Udden[76] has suggested that the narrowing of the post-Cretaceous folds west of the Marathon basin was caused by the competent nature of the deformed Paleozoic

[72] Letter from C. L. Baker, November, 1933.

[73] C. L. Baker, "Desert Range Tectonics of Trans-Pecos Texas," *Pan-Amer. Geol.*, *Vol.* 50 (1928), pp. 341–73.

[74] J. A. Udden, "Sketch of the Geology of the Chisos Country," *Univ. Texas Bull. 93* (1907), p. 85. See also Udden's "The Anticlinal Theory as Applied to Some Quicksilver Deposits," *Univ. Texas Bull. 1932* (1918), pp. 11–12.

[75] C. L. Baker and W. F. Bowman, "Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas," *Univ. Texas Bull. 1753* (1917), pp. 150–51.
P. B. King, "The Geology of the Glass Mountains," Pt. 1, "Descriptive Geology," *Univ. Texas Bull. 3038* (1931), p. 122.

[76] J. A. Udden, "Sketch of the Geology of the Chisos Country," *Univ. Texas Bull. 93* (1907), p. 76.

rocks below, but it should also be remembered that the eastern branch of the Sierra Madre is dying out northward.

North of the Marathon region, broad anticlines which lie somewhat east of the north end of the Del Norte Mountains continue with the same trend past the northeast end of the Davis Mountains to the Apache Mountains north of the Texas and Pacific Railway (Fig. 5). The folds both in the Del Norte Mountains and on the north involve Tertiary lavas[77] and are therefore, in considerable part, at least as young as Oligocene.

Between the western folds of the Sierra Madre and their narrower outer branch on the east is a structurally lower area. On the north it is occupied by the gently dipping lava flows of the Davis Mountains (Fig. 5), which, in part at least, are younger than the main deformation. South of the Davis Mountains, in the Chisos country, near the southern end of the big bend of the Rio Grande, is a broad synclinal area in which strata of late Upper Cretaceous age are preserved, and in which the base of the system extends several thousand feet below sea-level (Fig. 6).[78] West of the Chisos Mountains the strata rise into the broad, irregular, much faulted uplift of the Terlingua district,[79] in which Lower Cretaceous limestones are extensively exposed. This uplift culminates in the Solitario dome, in which the base of the Cretaceous lies more than 5,000 feet above sea-level. Northwest of the Terlingua uplift is a broad syncline in the Tertiary volcanics, beyond which Lower Cretaceous and Permian rocks rise again in the dome of the Chinati Mountains near Shafter (Fig. 5). The dome is truncated by erosion and overlain unconformably by lavas. The sedimentary rocks, and perhaps also the lavas, are intruded by large bosses of syenite and diorite.[80]

East of the eastern branch of the Sierra Madre in Texas is the Marathon dome (Fig. 6), a broad irregular uplift from whose central area the Cretaceous cover has been removed by erosion, exposing the deformed Paleozoic rocks of the Llanoria geosyncline. On the east flank of the dome, Cretaceous rocks slope toward Pecos River at angles of a few degrees or less. On the north and south flanks, their inclination is steeper and the base of the system descends from an altitude of more than 6,000 feet near the crest of the dome, to near

[77] C. L. Baker and W. F. Bowman, *op. cit.*, p. 142.

[78] The "sunken block" of Udden, *op. cit.*, pp. 80–87.

[79] J. A. Udden, "The Anticlinal Theory as Applied to Some Quicksilver Deposits," *Univ. Texas Bull. 1822* (1918), pp. 25–29.

[80] C. L. Baker, "Note on the Permian Chinati Series," *Univ. Texas Bull. 2901* (1929), pp. 79–82.

sea-level, a few score miles toward the north and south. The western edge of the Marathon dome is the sharp narrow fold of the Del Norte and Santiago mountains, overturned and thrust toward the west. South of the Rio Grande, in northeastern Coahuila, a similar broad dome, the Serrania del Burro has about the same structural height as the Marathon dome, but the Cretaceous cover is complete over its crest.[81] It is elongate northwest-southeast parallel with the Sierra del Carmen and other folds of the eastern branch of the Sierra Madre, which flank it on the southwest (Fig. 7).

Post-Cretaceous structural features related to Paleozoic trend lines.— Some of the post-Cretaceous structural features trend in directions seemingly parallel with the strike of the Paleozoic rocks beneath, rather than in the northwestward direction of the dominant folds of the Sierra Madre. These may have been produced by posthumous movements along Paleozoic trend lines. On the east slope of the Marathon dome several broad arches in the Cretaceous rocks extend nearly to Pecos River and trend in approximately the same direction as that suspected for the axes of the Paleozoic folds.

On the opposite side of the Marathon dome, Paleozoic rocks are again concealed by the Cretaceous, but on a southwest-trending belt through Green Valley, which connects the dome with the uplifted area near Terlingua and the Solitario, the rocks of this system stand much higher than they do in either the Chisos country on the southeast or the Davis Mountains on the northwest. They form a very broad, irregular arch (Fig. 6). Along the northwest side of the arch are many closely spaced, sub-parallel, short normal faults, similar to those in the Glass Mountains on the northeast flank of the Marathon dome (Fig. 6). It has been suggested [82] that the latter were formed in rocks overlying the northwest margin of the Marathon folded belt, and those on the southwest may have had a similar relation. That this arch which extends southwest from the Marathon dome may be related to the belt of folded Paleozoic rocks beneath is suggested by the outcrops of these rocks at the two ends, in the Marathon basin and the Solitario.

Some of the structural features southeast of the arch may also be related to Paleozoic trend lines. The synclinal basin of the Chisos country appears to have a northeast trend and to be aligned with several other synclinal areas south of the Marathon basin (Fig. 6). In that part of the Sierra del Carmen lying on the Texas side of the Rio Grande, the main northwest-trending axis appears to be

[81] W. S. Adkins, *op. cit.*, p. 298.

[82] P. B. King, *op. cit.*, p. 119.

crossed by minor northeast-trending arches, now greatly displaced and broken by normal faults (Fig. 6).

Structural events in late Mesozoic and early Tertiary time.—This survey of the stratigraphic and structural features of late Mesozoic and early Tertiary time permits some generalizations as to the sequence of events. In later Mesozoic time, after the Paleozoic structural features had become dormant, deposition began in western trans-Pecos Texas in a new geosynclinal area which crossed the older trend lines at an oblique angle. The first deposits laid down were confined to the geosynclinal area, and were sandstones and finer clastic sediments. Some of them were probably derived from marginal lands on the northeast, but the greater part probably came from farther west in Mexico. Over these was deposited a great mass of limestone, comparable to the early Paleozoic limestones of the southern Appalachian geosyncline. The mass thins northeastward toward the foreland, where successive parts change first into marly beds of neritic facies, and then into marginal sandstone deposits. Upper Cretaceous marine shaly beds follow, and change upward, in the region east of the geosynclinal area, into continental beds.

Cretaceous time was closed by a period of diastrophism, by which the western branch of the Sierra Madre appears to have been strongly folded and faulted, and the foreland area on the east thrown into broader folds and arches. After this movement the Cretaceous and older rocks were deeply eroded in the uplifted areas, and their fragments were distributed through the basal beds of the succeeding early Tertiary deposits. In early Tertiary time, lava flows and tuffs were spread over the worn-down surface of the foreland, resting in places on downfolded remnants of the highest Cretaceous, and in others on beds as old as the Paleozoic. At least locally they overlapped across the deformed geosynclinal rocks on the west.

After the period of early Tertiary volcanism there were further movements, by which the lavas were themselves deformed, chiefly along the trends of the preceding deformation. In most places the volcanic rocks were broadly arched and downwarped, but in some places in the west, along the edge of the strongly folded belt, thrust faults younger than the lavas have been found. In the eastern branch of the Sierra Madre near the Marathon dome, a considerable amount of broad folding appears to be younger than the lavas. The evidence for these different times of movement is not as complete as might be desired, because the late Cretaceous and early Tertiary rocks have not been worked out in detail, and because only a few fossils have been collected from them. Actually, the deformation may have been

accomplished by several more pulsations than the two suggested by the available evidence.

The steepness of many of the mountain ridges in both the eastern and western branches of the Sierra Madre, and the fact that a considerable number consist of uparched or upfaulted rocks, has led Baker[83] to suggest that most of their structural features are of late date. It seems unlikely to the writer, however, that all the deformation in the region took place at the same time. There have evidently been two periods of deformation. Moreover, the mountains may not have been uplifted to their present form and height during these times of folding, but may have been raised by later broad arching or normal faulting.

It should be remembered, also, that hard rocks in desert regions typically preserve steep and rugged slopes much later in the cycle of erosion than in humid regions. Mountain areas in the southwest thus rise abruptly from gently sloping, more extensive plains, even though many of them are relatively small erosion remnants of former highland areas, of which the plains are the worn-down parts. A large number of the mountains in trans-Pecos Texas consist of hard rocks; for example, the limestones of Lower Cretaceous age, which may possess either a monoclinal, anticlinal, or even (as at Malone Mountain)[84] a synclinal structure. The intervening lowland areas have been produced, not entirely by downfolding, but by the carrying away of non-resistant Upper Cretaceous rocks from synclinal areas, and of early Lower Cretaceous, late Jurassic, or Paleozoic rocks from anticlinal areas. Moreover, in structure sections across the anticlinal mountains, a reconstruction of the folds demonstrates that a great thickness of strata, now eroded away, formerly extended over their summits.

Relation of structural events in trans-Pecos Texas to sedimentation on the Gulf Coastal Plain.—In trans-Pecos Texas the structural events of Tertiary time can be deduced partly from the nature of the structural features, and partly from the older Tertiary rocks, most of which are of volcanic origin. Interpretations can not be perfect because of the fragmentary nature of the record and the small number of fossils which have so far been collected. In the Gulf Coastal Plain, east of the Sierra Madre of northeastern Mexico and trans-Pecos Texas, there was, during Tertiary time, more nearly continuous sedimenta-

[83] C. L. Baker, unpublished manuscript and letters to the writer, 1932–34.

[84] C. L. Baker, "Overthrusting in Trans-Pecos Texas," *Pan-Amer. Geol.*, Vol. 53 (1929), Fig. 1, p. 24.
N. H. Darton, "Guidebook of the Western United States, Pt. F, Southern Pacific Lines," *U.S. Geol. Survey Bull. 845* (1933), Pl. 17 B.

tion, and a more complete sequence of fossils. It is possible that events in the mountains have left their mark on the record in the coastal plain. The same pulsations may have influenced both regions. Moreover, the ancestral Rio Grande, flowing down the coastward slope from trans-Pecos Texas, and streams heading in the newly raised mountains in Mexico, must have carried large quantities of detritus to the coast, and probably influenced the character of sediments deposited there.

No very complete correlation between events in the two regions has ever been attempted, and it is a promising field for study. The record of events in the mountains is probably obscured in the coastal plain by the influence of structural events in other regions, by climatic changes, and by local factors which would cause fluctuations in the strand line.[85] The record should be plainest in the Rio Grande embayment and the coastal plain of Mexico, nearest the mountain area.

Cretaceous rocks are separated from the oldest Tertiary (Midway group) on the Texas coastal plain by a persistent hiatus and disconformity, and Baker reports that toward the Rio Grande and beyond in Mexico, the discordance is angular.[86] The succeeding Midway and Wilcox beds thicken southwestward by several thousand feet from Texas into northeastern Mexico.[87] Above the Wilcox in Texas, over a well-marked unconformity, is the coarse-grained and widespread Carrizo sandstone. Farther south, near Tampico, according to Baker,[88] the fine-grained clastic deposit of the Velasco shale (latest Cretaceous or earliest Tertiary), well developed toward the east, is replaced between the oil fields and the front of the Cordillera by the Chicontepec formation, in which beds of sand and gravel are interbedded with shale. The gravel consists of fragments of Lower Cretaceous limestone and chert, but the formation is folded equally with the older beds. These features of early Eocene stratigraphy are probably related to the first epoch of diastrophism in the mountains on the west.

The succeeding Eocene deposits of the Texas coastal plain are mostly fine-grained clastics, but toward the top sandstones are again prominent (Fayette) and there is an increasing amount of volcanic detritus (in Yegua and Fayette). Higher in the section is a marked

[85] F. B. Plummer, "Cenozoic Systems" in "The Geology of Texas," Vol. 1, "Stratigraphy," *Univ. Texas Bull. 3232* (1933), pp. 526–29.

[86] F. B. Plummer, *op. cit.*, p. 531.

[87] R. A. Jones, "Reconnaissance Study of the Salado Arch, Nuevo Leon and Tamaulipas, Mexico," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (January-February, 1925) p. 129.

[88] Personal communication from C. L. Baker, May, 1934.

unconformity at the base of the Catahoula formation, whose strata overlap the older beds and include coarse sandstones and great quantities of pyroclastic sediments.[89] At least a part of these are commonly believed to have come from the mountains on the west. The stratigraphic relations and a few plant fossils suggest that the Catahoula is of Oligocene age,[90] which is apparently in agreement with some of the determinations made on fossils from the volcanics in trans-Pecos Texas. North of Tampico Baker reports a similar unconformity and overlap at the base of the Oligocene.

Above the Catahoula formation in Texas is the Oakville sandstone, of Miocene age, which is also unconformable on older beds, and marks the first occurrence in the Texas Tertiary section of reworked Cretaceous rocks and fossils. It may reflect a pronounced uplift of the land behind the Balcones fault in central Texas,[91] but might it not also be related to the post-volcanic folding in trans-Pecos Texas? Unconformities are found higher in the section, at the base of the Goliad and the Lissie, and both formations contain much gravel. Many of the fragments in the latter clearly come from distant sources.[92] Perhaps the two formations reflect such later events in trans-Pecos Texas as the widespread block faulting, the regional uplift of the area, and the breaking through of the Rio Grande from its sources in Colorado. These events are discussed in the following paragraphs.

LATER TERTIARY AND QUATERNARY STRUCTURAL FEATURES

At numerous places in trans-Pecos Texas, the rocks are broken by faults which in ground plan are straight or angular, and with jagged offsets. Where the planes of such faults can be observed, they are either nearly vertical or dip steeply (60° or more) toward the downthrow, and are therefore probably normal faults. Where the rocks of the region are also folded, as in the southern part, the trend of the faults is roughly parallel with that of the anticlines and synclines, and this had led Baker to suggest[93] that they were formed during the folding of the region. However, where the writer has had an opportunity to study the detailed relations between folds and faults, as in the Glass Mountains and along the western edge of the Marathon basin, the parallelism is not perfect, and in many places

[89] F. B. Plummer, *op. cit.*, p. 720.

[90] *Ibid.*, p. 727.

[91] *Ibid.*, p. 734.

[92] *Ibid.*, p. 784.

[93] C. L. Baker, "Desert Range Tectonics of Trans-Pecos Texas," *Pan-Amer. Geol.*, Vol. 50 (1928), p. 372.

anticlines and synclines are cut cleanly across by faults. A similar relation may be suspected in the Sierra del Carmen, from inspection of geologic and topographic maps. The normal faults of this district are represented on Figure 6 as cutting across the folds. Moreover, where strong folding has taken place along the western edge of the Marathon basin, some of the larger normal faults are downthrown in a direction opposite to that of the overturning and thrusting of the strata. The writer therefore believes that these faults are a later feature than the folds, and that they were produced during a time of regional tension which followed the time of compression. He suggests that the earliest movements on the normal faults occurred in the late Tertiary.

In northern trans-Pecos Texas, most of the disturbance of the rocks is by such faulting. The region is divided into blocks many miles across, whose uplift, subsidence, and tilting has given rise to most of the present topographic features of the district. The rocks within the mountains are not conspicuously folded, probably because the area was relatively stable during the preceding time of compression. The relation between folding and normal faulting here is thus not clearly evident.

Faults of northern trans-Pecos Texas.—The outlines of a large part of the mountains of northern trans-Pecos Texas are determined by faults which lie along their bases. The edges of the mountains in places (as in parts of the Sierra Diablo and Delaware mountains) are remarkably straight and are dented only at intervals by the heads of alluvial fans. In other districts erosion has progressed farther and pediments embay the mountain slopes to such an extent that the original fault block form is lost. In many areas the fault trace is covered by thick alluvial-fan deposits, probably as a result of relatively recent uplifts of the mountain blocks, but locally even here (as along the edges of the Salt Basin, in the Guadalupe and Delaware mountains and the Sierra Diablo) small exposures of the downfaulted rocks crop out on the alluvial slopes in front of the escarpments. In some places there are also blocks (such as the Baylor Mountains east of the Sierra Diablo) which stand at a level intermediate between the rocks of the high mountains and those of the intermontane areas. Abundant exposures demonstrate that these owe their present position to faulting.

The intermontane areas of northern trans-Pecos Texas are apparently depressed blocks, lowered to their present positions by faulting. The two largest areas are the Hueco Bolson and Salt Basin on the east and west sides of the Diablo Plateau (Fig. 5). A smaller inde-

pendent basin, Eagle Flat, lies west of the Salt Basin in the latitude of Van Horn. These basins are filled by a great thickness of later Tertiary and Quaternary deposits. Some measure of the depression of the rocks in the intermontane areas may be gained from well records.[94] Several wells in the Hueco Bolson have been drilled to more than 2,000 feet, and one not far from the base of the Franklin Mountains near the New Mexico line to 4,920 feet, without passing out of basin deposits. In the Salt Basin a well drilled about 40 miles north of Van Horn went to 1,620 feet without leaving the basin deposits, and one 30 miles south-southeast of Van Horn encountered bed rock at 1,180 feet. In Eagle Flat a well was drilled to 1,000 feet without reaching bed rock.

The normal faults of northern trans-Pecos Texas have two general trends (Fig. 5). One system extends in general north and south, but it is highly irregular in detail, with some members trending north-northeast or north-northwest. The eastern boundary fault of the Sierra Diablo, a part of the system, has a bight and cusp pattern. In the Van Horn region the north-south system is crossed by another of west-northwest trend, most of whose members have less displacement than those of the first, but whose pattern is much more regular. Many of these show clear evidence of recurrent movements. Permian limestone reefs lie parallel with some of them and were probably formed during a flexing of the underlying rocks along the same trends as the later faults. Some others on the south side of the Sierra Diablo also show striking differences in the thickness of Paleozoic rocks on opposite sides. On one of these, for example, Cretaceous rocks rest on the pre-Cambrian on the downthrown side, while on the upthrown side they rest on 900 feet of Permian limestone and Cambrian sandstone. An earlier movement, the reverse of the recent one, evidently took place on this fault.[95] The recurrent movements along the west-northwest trending faults suggest that they coincide with persistent lines of weakness in the basement rocks of the region.

Movements on the normal faults have occurred several times. The eastern slope of the Franklin Mountains north of El Paso has been deeply embayed by pediments, yet at many places near its base is an escarpment 100 feet or more in height, produced by recent movements and composed partly of bed rock and partly of fanglomerate.[96]

[94] Well data chiefly from unpublished manuscript by C. L. Baker, 1934.

[95] This fault is shown at the left-hand end of Figure 25, in N. H. Darton, "Guidebook of the Western United States, Pt. F, Southern Pacific lines," *U.S. Geol. Survey Bull. 845* (1933), p. 125.

[96] First noted by G. B. Richardson, *U.S. Geol. Survey El Paso Folio 166* (1909), p. 9.

The lowest points on the floor of the Hueco Bolson on the east lie within a few miles of the base of these mountains, and from here eastward the basin floor slopes gently upward to the much lower Hueco Mountains. This slope may have been caused by recent tilting, perhaps at the same time as the last faulting. In the Sierra Diablo several canyons 5 miles or more in length drain eastward to the downfaulted block, and were probably extended headward from consequent streams draining the faces of the first fault scarps.[97] The mountain base line is, however, remarkably even, and is fringed with great alluvial fans still in the process of formation. In some places the fans themselves are broken by small faults, along which are escarpments 10 or 20 feet high. The floor of the Salt Basin on the east is, like the Hueco Bolson, asymmetrical, with a group of salt lakes in the lowest part, close to the high escarpments of the Sierra Diablo. The faults within the Sierra Diablo, including the west-northwest system, do not appear to have shared the last time of movement. Their scarps are considerably dissected, and the scarp bases are free from alluvial deposits. Several well marked high-level pediments and stream terraces in the south part of this mountain area (west of Beach Mountain) were apparently formed prior to its later uplifts.

Faults of southern trans-Pecos Texas.—A great fault system of general north-south or south-southeast trend has been mapped by C. L. Baker in the Sierra Tierra Vieja and southward along the west side of the Chinati Mountains beyond the latitude of Shafter (Fig. 5).[98] It may be considered as a southward extension of the system along the east side of the Sierra Diablo. The fault pattern as worked out by Baker consists of a number of parallel or *en échelon* fractures, with the greatest displacement now on one, and now on another. Most of the faults are downthrown to the west, in a direction the reverse of the overthrusting near by. In the north, bed rock is exposed on both sides of the main fault and here the throw is estimated at 2,000 or 3,000 feet; farther south the trace of the main fault follows the even western base line of the mountains and is mostly concealed by late Tertiary deposits. The rocks which cap the upthrown blocks are relatively non-resistant tuffs and lavas, and Baker suggests[99] that their preservation on the escarpments is evidence for the faults being of relatively recent age.

[97] G. B. Richardson. *U.S. Geol. Survey Van Horn Folio 194* (1914), p. 8.

[98] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), pp. 43-44 and Pl. 1, also later unpublished manuscripts and maps of the same author.

[99] C. L. Baker, "Desert Range Tectonics in Trans-Pecos Texas," *Pan-Amer. Geol* Vol. 50 (1928), p. 355.

Near Conchos River, in the strongly folded area of the western Sierra Madre, R. E. King has observed some large normal faults which have locally broken the folds. A small part of the topographic features of this region is probably caused by them.

In southeastern trans-Pecos Texas, normal faulting is not as pronounced as on the north, but is almost as extensive. The numerous faults in the belt between the Terlingua and Marathon uplifts and those in the Glass Mountains have already been noted. A great normal fault bounds the east side of the Mesa de Anguila (Fig. 6), and the Rio Grande cuts an imposing canyon through the fault block.[100] Another lies on the east side of the folded Santiago Mountains in the south part of the Marathon basin. The latter is not now shown by a scarp, and the upthrown block has been deeply eroded. The former stands as a high steep escarpment; non-resistant beds lie on its downthrown side, however, and it is probably a fault-line scarp.[101] The Sierra del Carmen is broken by numerous faults parallel with the long axis of the range.[102] Their apparent recency also may have been caused by the erosion of soft overlying beds from the surface of the Lower Cretaceous limestones. Baker[103] reports that south of the Rio Grande, fine-grained basin deposits lie against the face of the westernmost scarp without displacement.

Late Tertiary and Quaternary basin deposits.—During and after the first period of normal faulting the intermontane areas of the Basin and Range province were filled to a great depth by sediments, as suggested by the well records previously noted. Other areas of thick deposits are found farther south,[104] as in the Rio Grande valley west of Shafter, and there are smaller remnant areas west of the Sierra del Carmen. The upper parts of the basin deposits are well exposed along the Rio Grande, which has entrenched them to a depth of several hundred feet. Away from the mountains they are gray to flesh-colored silts,[105] in part gypsiferous, with some sandy lenses. Near the mountains they are interbedded with, and grade into, fan-

[100] J. A. Udden, "Sketch of the Geology of the Chisos Country," *Univ. Texas Bull. 93* (1907), p. 80.
F. B. Plummer, *op. cit.*, Fig. 27, p. 518.

[101] C. L. Baker, *op. cit.*, p. 356.

[102] C. L. Baker and W. F. Bowman, "Geologic Exploration of the Southeastern Front Range of Trans-Pecos Texas," *Univ. Texas Bull. 1753* (1917), Pl. 6, Sec. 21.

[103] C. L. Baker, "Desert Range Tectonics of Trans-Pecos Texas," *Pan-Amer .Geol.*, Vol. 50 (1928), p. 358.

[104] C. L. Baker, "Exploratory Geology of a Part of Southwestern Trans-Pecos Texas," *Univ. Texas Bull. 2745* (1927), pp. 37–40.

[105] N. H. Darton, *op. cit.*, Pl. 17 A.

glomerates and mud-flow deposits. The silts were probably deposited in broad, shallow, and perhaps intermittent lakes. Bones of *Elephus* and *Equus* of Pleistocene age have been collected by Richardson[106] near El Paso, either from the uppermost part of the deposits or from later gravels which lie unconformably above them. The age of the greater part is unknown. Pliocene or late Miocene fossils have been collected from similar beds in northern New Mexico.[107] In some places the deposits are faulted[108] and tilted.[109]

On the piedmont slopes east and west of the Franklin Mountains near El Paso, and probably farther southeast along the Rio Grande, the upper surface of the basin deposits is apparently a pediment rather than an aggraded slope. Overlying the deposits unconformably are coarser fanglomerates and terrace gravels of small thickness. Similar relations are reported along the course of the Rio Grande on the north in New Mexico.[110] The later faulting of the mountains may be related to these younger deposits. In the Salt Basin, where no recent dissection has taken place, the older basin deposits are probably not exposed. The surface materials here include gypsum dunes and beds of salt in the center, and coarse fanglomerates, which are apparently related to recent faulting at the margins.

River systems of trans-Pecos Texas.—Two important rivers, the Pecos and the Rio Grande, bound the east and southwest sides of trans-Pecos Texas. Their origin and history are in some way related to the development of the later structural features, but as a whole they have not been studied with care. In places their relation to adjacent land forms seems to be anomalous, and they possess many features which have yet to be explained.

The Rio Grande, in its course southeastward from the Sierra del Carmen to the coast, is apparently a consequent stream, which follows the structurally low areas down the regional dip of the beds (Fig. 7). On the northwest in trans-Pecos Texas, however, its course lies in a succession of intermontane desert basins, which it crosses at an oblique angle (Fig. 5). It passes from one basin to another through separating mountain barriers in gorges cut on bed rock. Thus the river crosses the Sierra del Carmen in the great canyons below Boquillas, and the Mesa de Anguila through the impressive Grand Can-

[106] G. B. Richardson, *U.S. Geol. Survey El Paso Folio 166* (1909), p. 6.

[107] N. H. Darton, "'Red beds' and Associated Formations in New Mexico," *U.S. Geol. Survey Bull. 794* (1928), p. 57.

[108] G. B. Richardson, *op. cit.*, p. 9 and Fig. 13.

[109] C. L. Baker, *op. cit.*, p. 40.

[110] Personal communication from Kirk Bryan, July, 1933.

yon of Santa Helena. In the western corner of the state it passes from the Mesilla Bolson eastward into the Hueco Bolson through a less impressive rock gorge above El Paso, the Paso del Norte of early Spanish travelers. A course partly through desert basins and partly through gorges in the mountains is also followed by the Rio Conchos in northeastern Chihuahua (Fig. 7). The relations of the Rio Grande in New Mexico are similar, save that its course is more nearly parallel with the dominant structural trends, so that it flows for longer distances through desert basins, and crosses mountain ranges in fewer places.[111]

Through all its long course from its sources in the Rocky Mountains in Colorado to the sea, the river receives few tributaries. From northern New Mexico to the Sierra del Carmen only one important stream contributes water, the Rio Conchos of Chihuahua. Not far east of the Sierra del Carmen the Rio Grande receives the waters of the Pecos, a stream which is nearly as long as the upper part of the main river, and which, like it, heads in the Rocky Mountains.

In its course across the desert basins the river flows in a well defined, level-bottomed valley, which near El Paso has been cut about 250 feet below the floor of the Hueco and Mesilla bolsons. Near Elephant Butte Dam in New Mexico, Lee reports that the river lies 450 feet below the surface of the Jornada del Muerto. The flood plains are underlain by sands and water-worn gravels to a thickness of less than 100 feet.[112] Terraces at levels intermediate between the surfaces of the desert basins and the flood plains of the river may be observed at many places. In many of the gorges, the highest bed rock seems to rise no higher than the level of the bolson deposits on either side, and at those places where the river crosses a continuous mountain barrier, the point of crossing seems to be structurally lower than that part of the mountains farther north or south.[113]

The basin deposits of trans-Pecos Texas adjacent to the course of the Rio Grande show no evidence of the existence of a large river at the time of their deposition. They consist in greater part of fine silts, and the only fragmental materials are the angular débris washed into them from the adjacent mountain ranges. This agrees with the record in the coastal plain near the Rio Grande. Gravel of distant origin appears first in the coastal plain section only in the

[111] The best published description of this part of the Rio Grande valley is that of W. T. Lee, "Water Resources of the Rio Grande Valley in New Mexico," *U.S. Geol. Survey Water Supply Paper 188* (1907). Many of his interpretations do not harmonize with modern ideas, but his observations are still valuable.

[112] G. B. Richardson, *op. cit.*, p. 6.

[113] This latter feature was noted in the Sierra del Carmen by Udden, *op. cit.*, p. 80.

Pleistocene (Lissie) deposits.[114] In New Mexico, however, near Albuquerque, Bryan[115] has found in the late Tertiary basin deposits "river gravels quite similar to those of the existing stream." He considers it likely that a river existed here as far back as Miocene time. Lee also reports that rounded pebbles of quartzite and argillite have been encountered in water wells in the central parts of the Jornada del Muerto and the Mesilla Bolson.

Pecos River, unlike the Rio Grande, crosses no mountain barriers, but follows the eastern side of the mountains through New Mexico and west Texas. Some miles east of the Pecos, beyond a pronounced west-facing escarpment, is the level surface of the High Plains, underlain by several hundred feet of Pliocene deposits. These are commonly supposed to have been washed out from the mountains west and northwest of Pecos River.[116] As evidence for this conclusion may be cited the apparent beheading of the upper tributaries of the Colorado, Brazos, and Canadian rivers by the Pecos, and the high level surface in the Sacramento Mountains west of the Pecos valley described by Nye. The latter can be projected eastward across the valley into the plains surface.[117] At some time after the deposition of the Pliocene deposits, for causes not well understood, the Pecos established itself parallel with the mountain front, and at right angles to the pre-existing drainage.

In its lower course, from the crossing of the Santa Fe Railway east of Fort Stockton southward (Fig. 5), the Pecos flows on bed rock, and has carved a canyon through the Edwards Plateau hundreds of feet deep. Farther upstream, in the Toyah basin, it flows over alluvial deposits 500–1,000 feet deep.[118] Many geologists believe these to have been deposited because of a subsidence of the basin floor, caused at least in part by the leaching out of Permian salt beds beneath. In the Roswell basin, north of Carlsbad in New Mexico, alluvial fill somewhat greater than 250 feet has been encountered, although between it and the Toyah basin alluvial deposits beneath the channel

[114] F. B. Plummer, *op. cit.*, p. 784.

[115] Letter from Kirk Bryan, October, 1929.

[116] F. B. Plummer, *op. cit.*, Fig. 51, p. 770.
S. S. Nye, "Geology" in "Geology and Ground Water Resources of the Roswell Artesian Basin," *U.S. Geol. Survey Water Supply Paper 639* (1933), pp. 96–97.

[117] F. B. Plummer, *op. cit.*, p. 771.
S. S. Nye, *op. cit.*, Fig. 1, p. 11, and p. 97.

[118] First reported by G. B. Richardson, "Report of a Reconnaissance in Trans-Pecos Texas North of the Texas and Pacific Railway," *Univ. Texas Bull. 23* (1904), pp. 79–80. Described in various later reports, including an unpublished paper by H. S. Gale on the geology and underground water of the Toyah basin, submitted to the United States Geological Survey for publication.

of the river are in places only 50 feet deep.[119] Nye describes four distinct terrace surfaces in the vicinity of the Roswell basin.

Structural events of late Cenozoic time.—The first epoch of normal faulting, probably of later Tertiary (Miocene or Pliocene) age, apparently disturbed nearly all of trans-Pecos Texas, but its effects were greatest in the north. During and after this epoch, basin deposits were laid down to great thickness in the lower fault blocks. There is no evidence that these areas were connected by any large streams. The sediments were probably derived from the immediately adjacent mountains, and were deposited in broad shallow lakes or playas. Toward the end of the epoch of basin filling, their surfaces may have been built up to such a height, and pediments cut back from them so far, that they were more or less connected with adjacent basins at the lowest points on the encircling mountain barriers.

Later movements apparently took place along the faults of northern trans-Pecos Texas, and continued until relatively recent time. During this time the mountains of the area, which had been greatly eroded during the epoch of basin filling, were again uplifted, and assumed their present form and height. The older basin deposits were somewhat deformed and new deposits were laid down unconformably over the old at the bases of the mountains. Probably few or none of the faults of southeastern trans-Pecos Texas were affected by the later movements. The escarpments which follow them are probably fault-line scarps, many of which are now deeply eroded. Those few which are straight and fresh seem to have been covered at one time by soft, easily removable strata on the downthrown block.

It is probable that the Rio Grande did not take its course across New Mexico and western Texas until long after the first time of faulting, and after the time of basin filling. The first evidence of river action to be seen is in the pediments and terraces eroded on the upper surface of the basin deposits.

The lower consequent course of the river, between the Sierra del Carmen and the gulf, probably came into existence much earlier. This ancestral stream may have made important contributions of sediment to Tertiary formations on the gulf coast as far back as the Eocene. An older river may also have existed in central New Mexico, as suggested by the evidence of Lee and Bryan. Lee supposed that for a time this stream did not flow to the sea, but emptied southwestward into the basin of Laguna Guzman, in northern Chihuahua west of El Paso.

[119] S. S. Nye, *op. cit.*, p. 26.

What could have caused the integration of these disconnected and wholly unrelated streams? A clue has been given by Blackwelder in a recent paper on the origin of Colorado River,[120] a stream which has many of the same peculiar relations as the Rio Grande. Blackwelder points out that there is evidence of great uplifts in Pliocene and Pleistocene time in the Rocky Mountain region. If such occurred there must have been a marked increase in rainfall in a region that had previously been low and semi-arid. Much water must have been shed off toward the south and southwest, filling near-by desert basins to their rims, overflowing into adjacent lower basins, and eventually establishing through-flowing drainage to the sea. One such through-flowing stream was the Colorado, another the Rio Grande. The increase in the amount of run-off may also have aided the Pecos in establishing its course east of the mountains.

The waters that shed south from the Rocky Mountains may have followed for a distance the river supposed by Bryan and Lee to have existed earlier in central New Mexico. If, however, this stream led to an interior basin, as supposed by Lee, the waters soon sought an outlet into adjacent basins. If the basins had previously been made partly confluent by prolonged filling and pediment cutting, this process may have been easy. That the waters found their outlet to the southeast across trans-Pecos Texas was largely fortuitous, and depended entirely on the accidental placing of the structurally low areas. The establishment of through-flowing drainage from Colorado to the sea was perhaps aided in mid-course by uplifts of mountains in Mexico. R. E. King[121] finds that in the Sierra Madre Occidental of western Chihuahua there is a widespread mature surface of broad valleys and low rolling divides at elevations of 6,000–8,000 feet, which is now being dissected on its west side by tremendous canyons. The uplift of this surface may have given rise to the Rio Conchos, and perhaps for a time to other streams, which joined the Rio Grande west of its crossing of the last mountain barriers. After crossing the last mountain range, the Sierra del Carmen, the waters from the Rocky Mountains, augmented by those from Mexico, joined the ancestral Rio Grande, which had previously existed east of the mountains on the coastal slope.

The subsequent history of the Rio Grande has been one of downcutting. This is expressed in most of its course by the trenching of the basin deposits, and the cutting of gorges in the more resistant rocks.

[120] Eliot Blackwelder, "Origin of the Colorado River," *Bull. Geol. Soc. Amer.*, Vol. 45 (1934), pp. 551–65.

[121] R. E. King, personal communication, April, 1933.

In the basins nearest the sea, such as that between the Sierra del Carmen and the Mesa de Anguila, greater quantities of non-resistant rocks were probably carried away, causing such knots of hard rock as the intrusives of the Chisos Mountains to stand out in bold relief. The deep cutting in the southeastern basins also permitted the river to be superimposed on lower folds and fault blocks, such as Mariscal Mountain, which had hitherto been concealed. It is possible that some of the fault blocks in southeastern trans-Pecos Texas were, at about this time, subject to renewed normal faulting, and that the stream cut down through them as they were raised. The river has, in fact, been interpreted by some geologists as antecedent to many of the fault blocks, and even of the folds, but most of the supposed cases of antecedency are subject to alternative interpretations. Until further evidence is obtained, it seems most probable that the river is either consequent to or superimposed on most of the structural features which it crosses.[122]

[122] Interpretations very similar to those here presented have been made by C. L. Baker, in "Desert Range Tectonics of Trans-Pecos Texas," *Pan-Amer. Geol.*, Vol. 50 (1928), p. 363, and the writer wishes to acknowledge his indebtedness to this earlier paper. In Baker's unpublished manuscript on the structure of trans-Pecos Texas, similar theories and some of the alternative hypotheses are discussed in some detail.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 262-270, 7 FIGS.

UPPER PERMIAN FORMATION OF DELAWARE BASIN OF TEXAS AND NEW MEXICO[1]

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Washington, D.C.

ABSTRACT

The purpose of this paper is to define and name the formations of the Delaware basin of Texas and New Mexico above the Delaware Mountain formation, that future discussions of the stratigraphy of the area may be facilitated. Something of the relationships and characteristics of these formations are given. The question of the age of the Bissett formation is also discussed.

The Delaware basin is a structural depression of roughly circular outline that had its maximum development during upper Permian time and was an area of more intense negative movement than the main Permian basin, of which it is a part. It lies beneath southern Lea and Eddy counties, New Mexico, and Culberson, Reeves, Jeff Davis, Brewster, Pecos, Ward, Winkler, and Loving counties, Texas (Fig. 1). Within this basin accumulated the greatest thickness of upper Permian deposits known in the Southwest. They are composed chiefly of chemical precipitates, with fine clastic shales and sandstones and some magnesian limestones of questionable organic origin. Although these deposits extend eastward and northeastward over the rim of the basin, they are nowhere so characteristically presented as in the Delaware basin.

In the Means well, drilled in 1921, in central eastern Loving County, Texas (SE. corner of Sec. 23, Blk. C–26, P.S.L.), a complete section of the upper Permian formations of the Delaware basin above the Delaware Mountain formation was penetrated. The Eldridge core test, an offset to the Means well, drilled in 1926, northeast of Section 22, to 1,192 feet, supplements the upper part of the Means well, and together they provide type material for the formations of the Delaware basin. Representative outcrops of these formations are not to be found because of their alteration on exposure at the surface, variation and change in lithologic character from subsurface to outcrop, or failure to crop out.

[1] Manuscript received, October 12, 1934. Published by permission of the director of the United States Geological Survey.

[2] United States Geological Survey.

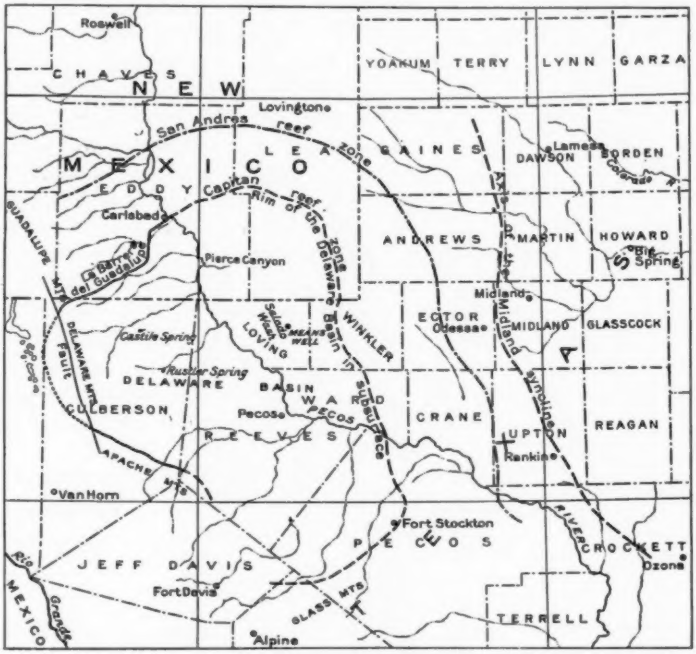

FIG. 1.—Map showing location and outline of Delaware basin, main axis of Permian basin (Midland syncline), Capitan and San Andres reef zones, and locations of geographic features which have given name to formations of Delaware basin.

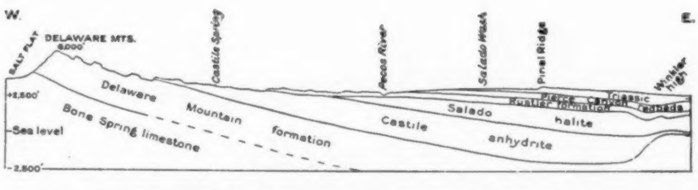

FIG. 2.—Diagrammatic cross section of Delaware basin from Salt Flat to Winkler County, just south of Texas-New Mexico boundary. Horizontal distance covered equals 100 miles; vertical scale greatly exaggerated in order to give appreciable thickness to Rustler and Pierce Canyon formations.

The Triassic red-beds are present from the surface to a depth of 200± feet where these wells were drilled, the plane of contact between the Triassic and the Permian being indeterminable at this place within 10± feet. Below this depth, and continuing to 550 feet, is a series of fine sandy to earthy red-beds, polka-dotted with green reduction spots and usually irregularly veined with thin secondary selenite fillings. The color and texture of the red-beds are nearly uniform, and the thickness of 350 feet represents what may be expected over most of the basin, the marginal areas and the Pecos Valley of Reeves County excepted. Although no favorable exposures are to be found anywhere, a fair outcrop is present in the vicinity of Pierce Canyon, southeast of Loving, New Mexico. The name Pierce Canyon red-beds is therefore given to this formation.

Beneath the Pierce Canyon red-beds and separated from them by an unconformity is the Rustler formation. The Rustler in subsurface is different from that in outcrop in the original type section.[3] It begins at the top with a massive anhydrite bed 30 feet thick. The section is here shown.

		Depth (Feet)	*Thickness (Feet)*
	Anhydrite	550–580	30
Upper anhydrite member	Anhydrite with sandy, gypsiferous, and red-bed breaks	580–700	120
	Red shale with brecciated gypsum and anhydrite	700–751	51
Upper limestone member	Limestone, magnesian and cellular	751–782	31
	Red-beds	782–803	21
	Anhydrite	803–820	17
Sandstone member	Sandstone, gray, very fine-grained, finely laminated and cross-bedded	820–900	80
Lower limestone member	Limestone, magnesian, cellular	900–911	11
Basal red-beds	Red-beds, fine sandy to earthy, with anhydrite breaks and showing of halite crystals	911–920	9
			370

The Rustler is a variable formation, though its general characteristics are such that it may readily be recognized in subsurface (Fig. 3). The two tongues of dolomitic limestone, everywhere cellular and in many places oölitic, are usually present, and they extend across

[3] Rustler Spring, Culberson County, Texas.
G. B. Richardson, "Reconnaissance in Trans-Pecos Texas," *Univ. Texas Bull. 23* (1904), p. 44.
———, *U.S. Geol. Survey Van Horn Folio 194* (1914), p. 6.

the Delaware basin, feathering out in the east-central portion of the main Permian basin in about the position of the axis of the Midland syncline. On the west, across Pecos River in Culberson County, the upper limestone member expands and becomes the dominant representative of the Rustler, for here the incursion of fresher brackish waters from the west during Rustler time caused the accumulation of calcium and magnesium carbonates in excess of other precipitates. East of the Pecos, lenticles of rock salt with occasional showings of

FIG. 3.—Core of Rustler sandstone member from second Government potash test in Eddy County, New Mexico. Depth, 242 feet. Sandstone composed of sharp, clear, relatively uniform-size quartz grains with diameter of 1/50 mm. or less. Quartz grains contain some fine inclusions. Accessory minerals of pyrite, mica, pyroxenes, et cetera, make up no appreciable percentage of washed grains. Very small amount of dolomitic cement with organic material makes weak binder for sand grains. Dark bands due to excess of organic material. Sandstone member banded throughout and commonly very minutely cross-bedded. Banding of sandstone, though very much finer, is similar to that of Castile. Size, ×0.8.

polyhalite are to be found. Although the Rustler usually maintains a thickness of 300–400 feet, it may locally approach 1,000 feet in thickness. In the Eldridge core test it extends from a depth of 550 to 920 feet, where it is separated from the underlying salt series by a major unconformity.

In 1923 the writer recognized that the salt section was divisible into two major units and orally introduced the terms "Upper" and

"Lower" salt series, the basis for the separation at that time being that the "upper" part is shaly, pinkish, and on analysis generally shows more than 1 per cent of K_2O, whereas the "lower" has a dull grayish appearance and on analysis yields less than 1 per cent of K_2O. The upper salt series is dominantly composed of rock salt with massive anhydrite beds, red-beds, shaly sands, and prominent beds and lenses of polyhalite[4] that are characteristic only of this formation. Also in the upper part of this upper series are to be found local con-

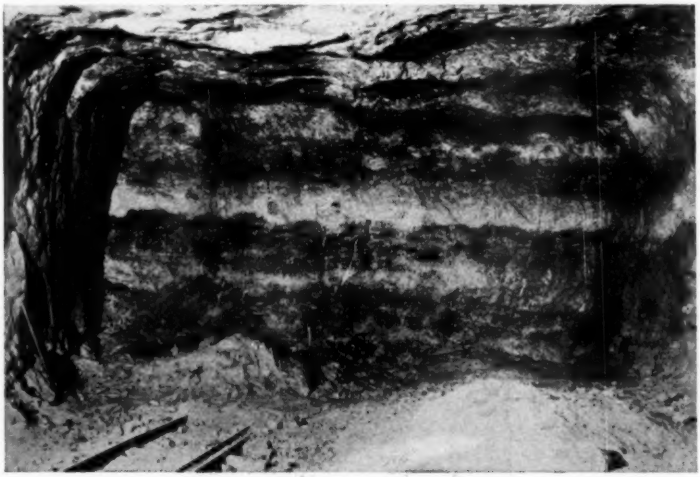

FIG. 4.—Heading in potash ore in one of tunnels of United States Potash Company's mine, Eddy County, New Mexico. Tunnel cut in mixture of halite and sylvite averaging 25–30 per cent K_2O. Banding depositional and characterized by lean and rich layers of red sylvite intermixed with white sylvite and halite, sparingly sprinkled with blue halite, a little gray-green shale, and here and there a stringer of polyhalite. Halite and sylvite make up more than 98 per cent of rock.

centrations of the chloride and sulphate salts of potassium, of which sylvite, carnallite, and langbeinite are the essential representatives and which are exposed in the potash mine shafts some 20 miles east of Carlsbad (Fig. 4). Although this upper salt series underlies an area of more than 60,000 square miles, it has no definitely known outcrop, the nearest approach to an outcrop being in eastern Culberson County. Here weathering has so deeply altered the anhydrite to gypsum that if the disrupted anhydrites of the upper series were present they would

[4] Polyhalite is now known to exist in the Permian basin of the Southwest in massive beds of such thickness and extent as to raise this mineral to the status of a rock.

be difficult to recognize. The name Salado halite is given to this upper salt series, from Salado Wash[5] in northern Loving County, Texas—salado being the Spanish word for "salted." The Salado halite has suffered pre-Rustler erosional truncation in Eddy County, New Mexico, and in Reeves, Culberson, and western Loving counties, Texas,

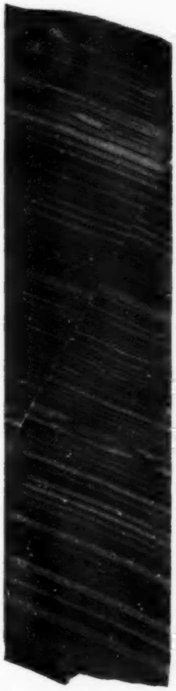

Fig. 5.—Banded anhydrite from Castile. Flood core test in Culberson County Texas. Depth ,1,385 feet. Dark thin bands chiefly calcite with included organic material; lighter-colored wider bands are anhydrite, also containing some organic material. Angular attitude of laminae does not indicate true dip of formation but represents mild local undulations. Fault of small displacement cuts across core. White specks are gypsum crystals, initial points of alteration of anhydrite to gypsum. Polished section. Half natural size.

and has also been affected in those areas where the more prominent reef masses accumulated. It extends in the Means well from the depth of 920 feet to 2,350 feet.

[5] That part of the Pecos River in Texas was known to the early Spanish explorers as the Rio Salado.

The lower salt series crops out in Eddy County, New Mexico, and Culberson County, Texas. It is the formation to which Richardson[6] gave the name Castile gypsum as including all rocks between the Delaware Mountain and Rustler formations (Fig. 5). Richardson was not then aware of what is now revealed in the well logs.[7] As the outcropping gypsum is part of or represents the lower salt series and is only a surficial alteration by weathering of the main mass of anhydrite in subsurface, it seems fitting to apply to the lower salt series the name Castile anhydrite. The Castile anhydrite extends downward from 2,350 to 4,990 feet, where it lies unconformably on the Delaware Mountain formation. Within the Delaware basin proper the uncon-

FIG. 6.—Chemically deposited limestone from Castile. Consists of laminae of calcium carbonate, darker bands being more heavily impregnated with carbonaceous material. These limestone members crop out on eastern slope of Delaware Mountains and are common to basal portion of Castile. Half natural size.

formity is without angular discordance. The Castile is composed of massive beds of gray anhydrite, clean white rock salt, dolomitic and crystalline limestones that are chemical precipitates, and some sandstones. Many of the salt members of both formations interfinger into anhydrite west of Pecos River, and the Castile in some places becomes all anhydrite.

The crystalline limestones and the anhydrite[8] are typically laminated in bands 1.5 to 2 mm. thick (Fig. 6). Although these bands or "varves"[9] are most conspicuous in the Castile, they are by no means confined to it. On the contrary, rhythmical deposition is expressed in all of the sediments of the Delaware basin, although it is sometimes

[6] G. B. Richardson, *op. cit.*, "Reconnaissance," p. 43; *Folio*, p. 6.

[7] Oral communication.

[8] J. A. Udden, "Laminated Anhydrite in Texas," *Bull. Geol. Soc. America*, Vol. 35 (June 30, 1924), pp. 347–54.

[9] In a forthcoming paper it is intended to show that these laminations represent annual periods of time.

difficult to detect. Even uniform, fine-grained, dense polyhalite that has been produced by the alteration of anhydrite will, on careful inspection, invariably disclose "varves" of approximately 5 mm. thickness (Fig. 7). Partially disrupted bands in polyhalite from the top of the Salado in the Eldridge core test are 10 to 12 mm. thick.

On the northwest slope of the Glass Mountains is a series of conglomerate, sandstone, red-bed and dolomitic limestone deposits known

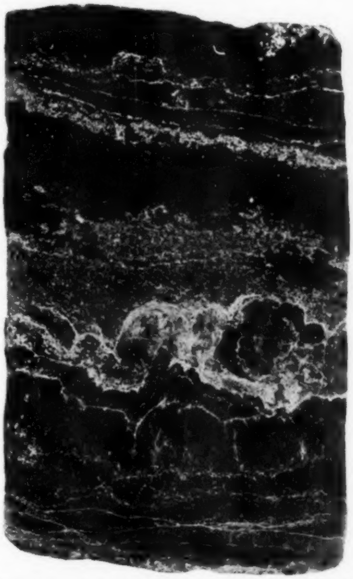

FIG. 7.—Polyhalite from Salado halite at 1,383 feet in thirteenth Government potash test, Eddy County, New Mexico. Shows original banding of thin magnesitic clay seams and polyhalite and secondary blooms of polyhalite in process of modifying original structure. Size, ×0.8.

as the Bissett conglomerate.[10] It lies directly on an eroded surface of the Capitan and is composed of reworked material from the upper Permian formations. It is overlain unconformably by the Comanche and is unlike any of the associated formations. The meager fossil evidence[11] suggests that the Bissett is very closely related to the Per-

[10] P. B. King, "The Bissett Formation," *Amer. Jour. Sci.*, 5 Ser., Vol. 14 (September, 1927), pp. 212–21.

[11] "The Geology of Texas," *Univ. Texas Bull. 3232*, pp. 154–55.
Oral communication—David White now considers the Bissett as more probably Mesozoic than Permian—July, 1934.

mian and therefore can not be much younger. The position and material of this formation indicate that prior to deposition of the Bissett, erosion extended down to and including the Capitan, followed by mild folding in the Delaware foredeep, developing a pocket wherein accumulated the Bissett deposits. Such a sequence of events is not in keeping with the known Permian record as expressed in the northern and eastern portion of the basin, if the Quartermaster and Pierce Canyon deposits are the final overwash of Permian sediments.

The Bissett, to be Permian, must be a correlative of the Rustler or the Pierce Canyon or must be younger than the Pierce Canyon. It more closely resembles the Rustler than any of the upper Permian formations, and if Rustler, there should be found in the dolomitic members species of *Myalina* and *Pleurophorus*, as they are common in the Rustler, though not necessarily diagnostic. They have so far not been reported from the Bissett. It is believed that the Bissett represents an accumulation of lower Triassic sediments of possible Moenkopi time equivalence and therefore considerably older than the terrestrial Dockum and Santa Rosa deposits farther north, that exhibit the characteristics of the Shinarump and Chinle formations of northwestern New Mexico. The Pierce Canyon red-beds appear to be the last definite evidence of Permian sedimentation in the Southwest.

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EXPERIMENTS ON SOFT-ROCK DEFORMATION[1]

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ABSTRACT

The paper describes laboratory experiments illustrating deformation of soft sediments produced by slump, differential movement, and differential loading. It explains some of the structures developed, and suggests criteria by which soft-rock deformation may be differentiated from hard-rock deformation.

INTRODUCTION

Study of rock deformation and of the structure of the earth's crust is a branch of geology which lends itself to experimental consideration. Many experiments have been performed to determine the nature, character, and origin of folds and faults. These experiments were carried out with plastic and semi-plastic materials, and the conclusions drawn from them have in practically all cases been applied to hard-rock deformation. The various authors performing these experiments have chosen materials whose plasticity or rigidity seemed most nearly to represent that of the rocks under consideration and have deformed them, in most cases, by a piston thrust from one end. The experimental work described in this paper differs from most of the previous experiments in that the materials used were actual sediments. The ideal experiment should, of course, reproduce as nearly as possible all of the conditions of the natural occurrence. Such an ideal, however, is rarely possible, and experiments usually must be miniature reproductions subject to a more or less loose interpretation. The writer realizes these limitations and, in most cases, does not regard the results of his experiments as of particular significance, if interpreted too precisely on a large scale.

The experiments were conducted by the writer in the Sedimentation Laboratories of the University of Wisconsin and of Cornell University. The writer wishes to acknowledge the valuable aid of W. H. Twenhofel and C. K. Leith of the University of Wisconsin, and of H. Ries of Cornell University.

[1] Manuscript received, October 29, 1934.

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DEFINITION OF TERMS

"Consolidated" and "unconsolidated" are two terms found rather frequently in geologic literature. Although relative terms, they have more or less definite meanings, though the point at which a rock ceases to be unconsolidated and becomes consolidated is rather indefinite. An unconsolidated rock is one which easily falls apart under the hammer, or, in the case of muds, one which may be deformed by hand. The term is applicable to coarse or fine sediments, or to material deposited from solution. The terms "hard rock" and "soft rock" are used in this paper not because they denote more specifically the actual physical condition of the rock under consideration, but because the terms may be a little better associated with the word "deformation." In the experiments described, only fine-grained materials were used; that is, materials of the nature of muds and fine sands. As the most characteristic physical property of these substances is their softness, it is thought the term "soft rock" is not out of place.

"Contemporaneous deformation" also is a term which implies soft-rock deformation. This term, however, has had a slight qualification put upon it by Lahee,[3] who states that the term should be limited to those cases in which the distorted or deformed zone or structure is of the soft-rock type, actually cut by a local unconformity, a condition which suggests that the faulting or folding took place very close to the plane of deposition not long after the material was deposited, in other words, that the movement is nearly contemporaneous with the deposition. Soft-rock deformation thus differs from contemporaneous deformation in that it may take place at any time after the rock has been deposited and before it becomes hard.

Just when a rock becomes hard is a question for which no answer is attempted, as hardness is a relative term, and may vary under different sets of circumstances. Study of the failure of rocks shows that sudden movements may result in fracturing and breaking, whereas slow movements, causing the same relative displacements, may produce bending and folding. In this paper the terms hard and soft are used to denote the character of rocks as tested by the hand.

EQUIPMENT AND PROCEDURE

The experimental work was carried on largely in a galvanized iron tank, 5 feet long, 1 foot high, and 6 inches wide. It was fitted with plate-glass sides and four drains at one end for use in regulating the

[3] F. H. Lahee, *Field Geology* (3d ed., 1931), p. 78.

depth of water (Fig. 2). Another tank similar in size, but with a movable bottom, was used in the reproduction of faulted structures.

Use was also made of a sedimentation tank, 5 feet square and 1 foot deep, also fitted with glass sides, and so arranged that sediments might be introduced naturally by running water to produce various depositional forms.

For a long time difficulty was experienced in building up a series of beds in the tanks which would be suitable for experimentation. First attempts resulted in very irregular, jagged, and unnatural layers which would not readily show all of the effects of any movement to which they might be subjected. Ordinarily, deposition by running water was not found satisfactory because of the scouring effect of the water and the difficulty of obtaining uniform beds. After various methods had been tried, the following was devised. The tank was filled with water to the topmost drain. To produce a sand layer, sand was dried and then poured through a sieve of the proper mesh which was kept moving back and forth along the entire length of the tank. This procedure allowed the sand to settle slowly through the water so that the resulting layer would be quite uniform and natural in appearance. Banding was easily produced by introducing sands of different colors or by ceasing operations for a few minutes to allow the finer materials to settle.

Best results in making clay beds were obtained by fiıst reducing the clay with water to the consistency of "soup." Then, with a small pan or pitcher, this "soup" was poured into the tank with the water level near the top, and the clay allowed to diffuse through the water. It was found that when pouring the "soup" into the tank, it was better to hold the pan or pitcher actually in the water and to allow the clay mixture to run out very slowly. It is important in this process to have the clay mixture warmer than the tank water so that the difference in the specific gravities of the clay mixture and of the tank water is as small as possible. The idea in this manipulation is to "saturate" the tank water with clay and then to allow it to settle slowly.

Banding in the clay may be produced either by introducing the same clay at intervals, or by using clays of different colors. Results of the latter process are better, as the banding produced by interrupted deposition is largely textural and does not photograph well. Owing to the fact that the clay settles very slowly to the bottom, a week or 10 days may be required to build up a series of sediments of sufficient thickness for experimental purposes.

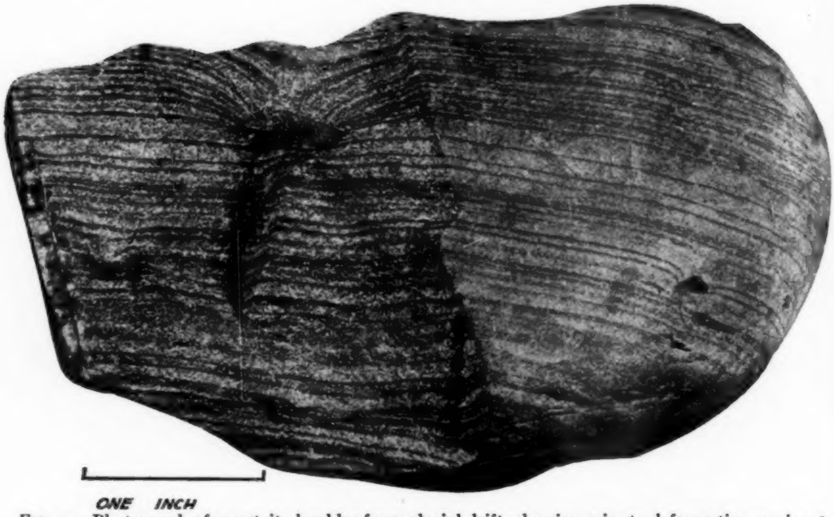

FIG. 1.—Photograph of quartzite boulder from glacial drift, showing minute deformation produced by objects falling into soft sediments.

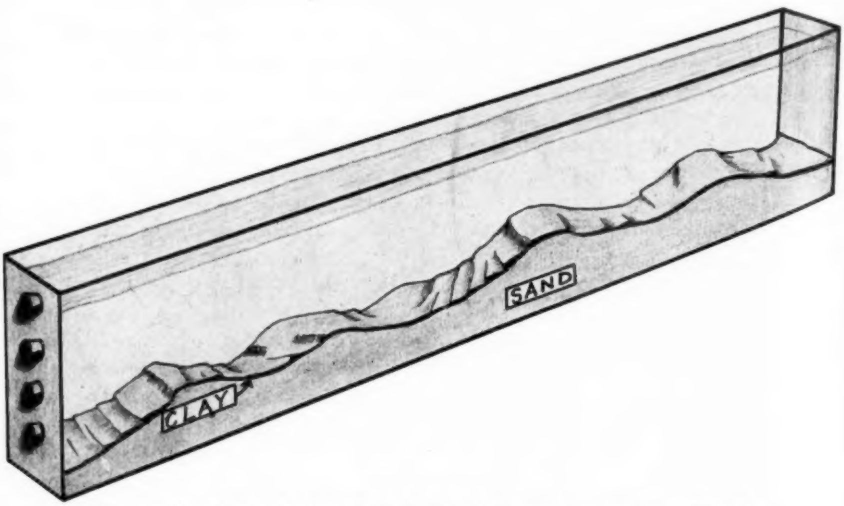

FIG. 2.—Experiment showing effects of slight jars upon clays resting on irregular surface. Length of tank, 5 feet.

DESCRIPTION OF EXPERIMENTS

DEFORMATION PRODUCED BY OBJECTS FALLING ONTO SURFACE OF SEDIMENTS

Although structural irregularities produced by objects falling onto the surface of sediments are quite small and localized, they may be important in determining such things as top and bottom of beds, and conditions obtaining at time of deposition. An example of this is shown in Figure 1. The rock pictured is an extremely hard quartzite found in the drift near Ithaca, New York. In the upper left portion of the specimen is an oval pebble which evidently fell onto the sediment while it was still soft. The pebble has broken through fully ½ inch of sediment. It will be noticed that the last band above the pebble is continuous, a fact which shows that the pebble fell on the surface of the sediment prior to the deposition of this last lamination. In the lower right portion of the specimen is a considerably smaller pebble which shows the same features.

Tests were made on some wet fine-grained sands by allowing pebbles of the size here pictured to fall from various heights (both in water and out of water). It was found that only with the loosest sort of packing would the pebble break through sand as did the pebble in the pictured specimen, even when the pebble was dropped from the height of a room ceiling. Most favorable conditions for penetration occurred when freshly deposited sands were covered with not more than one inch of water. Greater depths of water so retarded the fall of the pebble that only slight penetration took place. Less water resulted in a tighter packing of the sand and consequently less penetration. Experiments show, therefore, that the sediment from which this specimen came was probably under very shallow water at the time the pebble fell, and near shore, where it was exposed during low tide.

DEFORMATION DUE TO SUBAQUEOUS SLUMP

Deformation due to slump may be classified under two headings: (1) that occurring out of water, or subaerial; (2) that occurring under water, or subaqueous. By slump is meant the movement of material down a slope because of its incompetence to maintain itself against gravity.

Subaerial slump includes such movements as avalanches, landslides, rock streams, and mud streams. No experiments with this type of slump were attempted by the writer.

Subaqueous slides are no less important than subaerial slides, although references to recent occurrences of them are rather uncom-

mon in the literature. Heim,[4] who has described subaqueous slides, states that the average angle of slope of one slide in Switzerland was 2° 31′ and that the moving material extended 1,020 meters from shore. He also shows how parts of beds may be omitted or duplicated in the geologic column by the sliding of material away from one place and the piling up at another, the low-angle fault between them being so inconspicuous that error might arise in interpreting the sequence were the fact of the slide not known. Hahn[5] has described cases of subaqueous slump, pointing out that lens-like masses often break loose, slide down a slope and come to rest only after they have been considerably deformed and contorted. He concludes that the most intense part of the folding is near the front, and the trend of the folds is approximately at right angles to the direction of the moving mass.

Experimental efforts to gain quantitative information regarding the movement of slumping sediments brought out the fact that not much information could be obtained in the laboratory. Large masses of material measured in tons act quite differently from the small masses which can be handled in a laboratory. In nature, it has been observed that sediments will move on a slope of 2° or 3°, whereas in the experiments conducted by the writer, much greater slopes were needed to cause movement. In several instances during experimentation, the required gradient was as much as 20° even with the softest material. This point should be borne in mind when considering the following experiments.

Figure 2 brings out very nicely the effect of slump on an irregular surface. Sand was placed in the bottom of the tank and formed into an irregular surface by scraping with the hands. The water over the sand was then saturated with several small panfuls of clay "soup" which was allowed to settle to the bottom. As the clay settled, it formed a layer of equal thickness over all parts of the sand. A slight jar of the tank produced the results shown in the diagram. The clay migrated a slight distance down the dips, and actually formed itself into folds which were overturned in the directions of slope. Near the crests of the hills in every case, normal faults developed with the downthrown side down the slope of the hill. The association of overturned folds with normal faults may seem at first rather peculiar, but in slump movements it appears to be a natural relationship. It is evident that the movement of the mud naturally causes a pulling away of material near the crests of the hills with a consequent normal fault-

[4] A. Heim, "Über Recente und fossile subaquatische Rutschungen und deren geologische Bedeutung," *Neues Jahrbuch für Mineralogie*, Vol. 2 (1908), pp. 136–57.

[5] F. Hahn, *Neues Jahrbuch für Mineralogie*, Beilage Bd. 36 (1913), pp. 1–41.

ing. Further tapping of the tank causes continued slump and complete piling up of the material in the lower places. The experiment just described is easy to perform and, by varying the lengths and dips of the slopes, many interesting structures may be produced.

In working with series of sediments in the glass tank, numerous experiments in slumping were performed, all of which emphasized the same general conclusions. These experiments may be described or summarized by reference to a representative one pictured in Figures 3 and 4. In these experiments the procedure was practically the same in all cases, with the exception of the superposition and the relative quantities of various materials used. In each case the sediments were deposited with the tank in horizontal position and then caused to slump by raising one end of the tank.

The materials used consisted of a fairly clean sand of medium grain, a fine-grained sand containing considerable clay, a somewhat coarser sand, and bentonite. Mechanical analyses of the sands used are given below. They are numbered *1*, *2*, and *3* for the sake of convenience. Fractions are in percent of weight.

	1	*2*	*3*
On mesh 6	—	—	—
12	0.01	0.02	0.02
20	0.07	—	0.05
40	3.01	1.98	0.50
70	49.35	4.80	5.34
100	34.73	5.84	3.00
140	9.80	17.20	1.84
200	2.09	17.50	1.20
270	0.50	23.32	2.22
270	0.26	25.10	29.64
Clay	—	4.16	55.78
Total	99.82	99.92	100.04

The sediments in the tank are built up as follows. About 1½ inches of sand No. 1 were deposited upon the bottom of the tank. In the photograph this layer appears white. This sand was followed with about the same quantity of sand No. 2. Above No. 2 was deposited a layer of bentonite about ½-inch thick.[6] Over this were deposited about 3 inches of sands 2 and 3 alternately so as to produce banding, No. 2 being considerably lighter than No. 3.

Immediately after deposition of the sediments, the tank was tilted to an angle of about 7° from horizontal, when the mass began to slide along the bentonite layer as a gliding plane. Figure 3 shows the sediments after sliding, and Figure 4 is an enlargement of the lower end of the tank.

[6] The bentonite was caused to settle by adding a salt solution to the tank water.

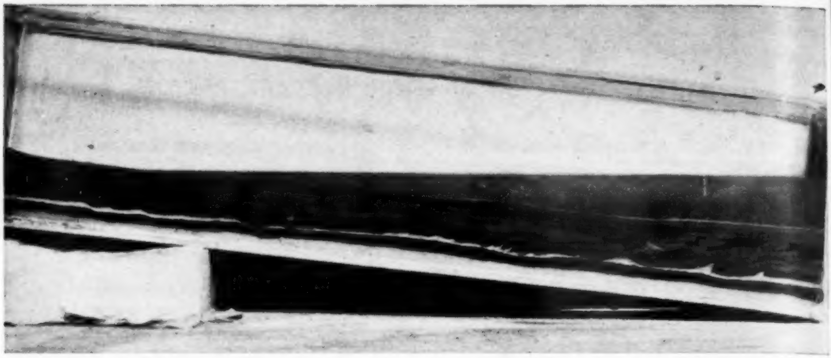

FIG. 3.—Deformation of sediments by slumping. It will be noticed that sediments are deformed in different ways at opposite ends of tank. Folding at upper end is simple, whereas at lower end there are overturned folds with axial planes dipping toward upper end of tank. Length of tank, 5 feet.

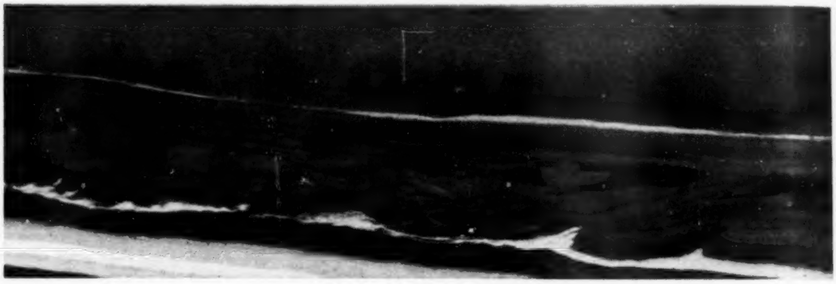

FIG. 4.—Enlargement of lower end of deformation shown in Figure 3.

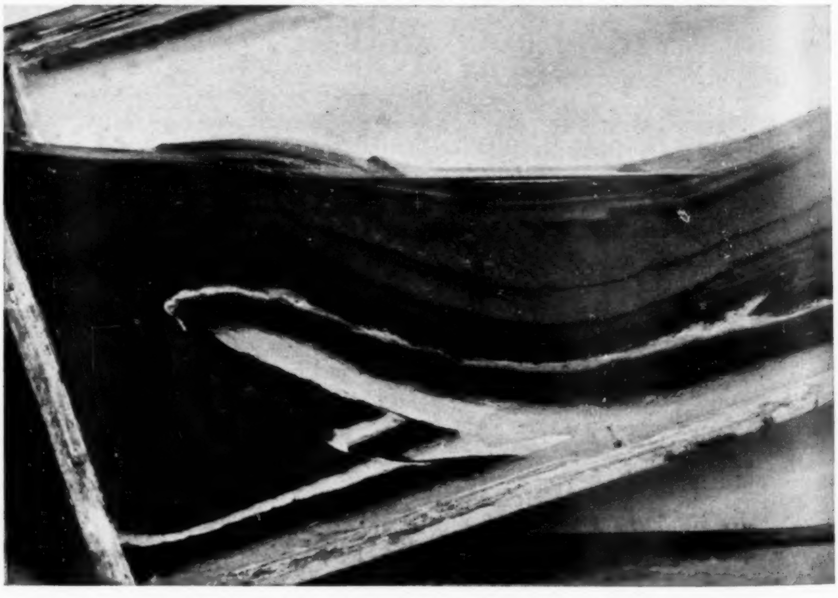

FIG. 5.—Overthrust due to slump. Tank has been tilted 20° from horizontal. Length of photograph, 18 inches.

After slumping had taken place, the surface of that portion of the sediments which was deformed was quite irregular. However, by slightly agitating the water in the tank, a small degree of subaqueous erosion was produced, and the irregularities disappeared. Over this smooth surface a layer of sand was deposited as shown in Figures 3 and 4.

Slumping, followed by slight erosion and subsequent deposition, produced a contorted zone, enclosed above and below by horizontal beds. Neither the upper nor the lower beds show the effect of the folding, nor do the beds above bow upward over the crests of the folds, as might be expected.

Figure 5 shows the development of overthrust faulting due to slump. The fault in this experiment, however, is probably not entirely natural, for its curvature and angle of dip are certainly modified by the buttress effect of the end of the tank. However, it shows very well the characteristics of faulting in soft material. The nature of the fault plane, the drag, and the distortion of the strata are characteristic. The materials used in this experiment were the same as those used in producing the experiments pictured in Figures 3 and 4, but the tank was tilted about 20°.

DEFORMATION DUE TO DIFFERENTIAL MOVEMENT

By differential movement is meant a movement caused by rotational forces such as the moving of one bed relative to another. It is distinguished from gliding or faulting only by the fact that the displacement has not taken place along a single plane. The results of such deformation show considerable similarity in the type and position of the structures produced. Examples of deformation definitely known to be due to differential movement of soft rocks are rather uncommon, most authors ascribing the contorted zone to slump or to the effects of some floating objects, and not stressing the rotational effects. Every geologist is familiar with the drag fold and its relationship to the major moving forces.

Considerable difficulty was experienced in reproducing drag folds and deformation due to differential movement. Many attempts were made with several types of sediments and numerous variations in manipulation were devised before satisfactory results were obtained. The result desired in the experiments was to produce a differential movement between two beds, and to form a folded zone between undisturbed beds above and below. Most attempts resulted in folding of the entire mass or a gliding along some clay beds without any folding.

The method which gave the best results is here described and illustrated in Figures 6 and 7.

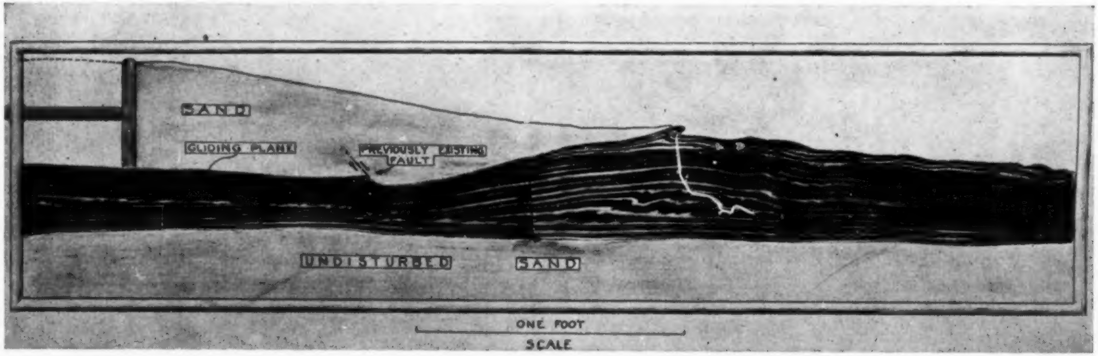

FIG. 6.—Results of differential movement showing formation of folded zone between relatively undisturbed beds. Fault is antecedent to piston thrust and is due to sand loading. (Illustration is combination photograph and drawing.)

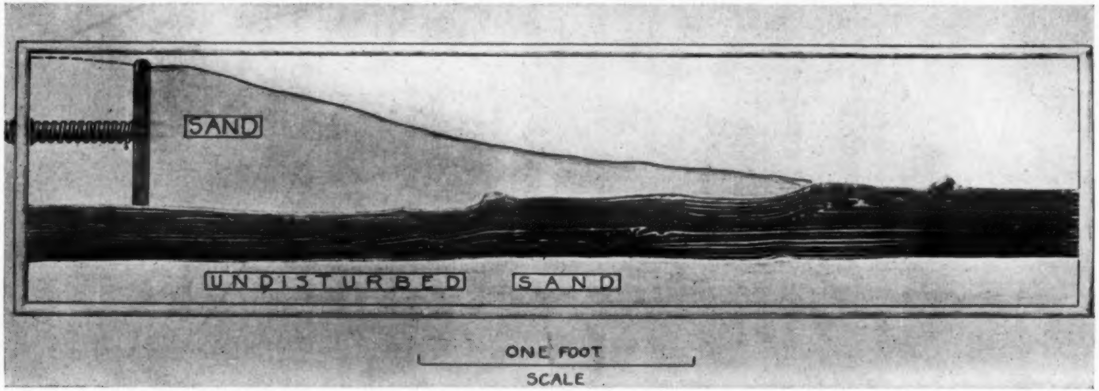

FIG. 7.—Experiment similar to Figure 6, showing variations in character of folded zones. As in Figure 6, faulting below sand occurred before piston thrust. (Illustration is combination photograph and drawing.)

The tank was first filled with water and then a layer of about 3 inches of fairly coarse sand was deposited on the bottom. On top of this sand, layers of extremely fine red and white pottery clays were deposited. In the photographs, the red clay appears black and the white shows its natural color.[7]

These clay beds were built up to a thickness of about 5 inches and the layers were remarkably uniform, showing only slight irregularities along the entire length of the tank. Sand, similar to that used for the lowermost layer, was then very carefully and slowly spread over one end of the tank, as shown in Figure 6, to the depth of 6 inches near the end and grading down to zero near the center. A wedge-shaped mass of sand, representing a delta deposit, was thus formed over the clay.

At the moment when the thickness of sand shown in the illustration had been deposited, faulting took place, with displacement in the underlying clay beds. This faulting was a result of differential loading and will be discussed later under that head. However, it should be stated that the faulting caused some slight folding in the clay.

After faulting had ceased, a piston was inserted behind the upper sand mass, and a force applied from left to right. The piston was moved about 7 inches to the right, causing a gliding plane to form in the clay beds which were under the load of sand. Where the sand load was small or absent, the beds took up this movement largely by folding, as shown in the photograph. The folds are drag folds and, with one exception, show the direction of movement of the overlying beds with respect to the lower. Just why this one fold should be reversed is not clear, but presumably it is due to the "excess" movement of the beds immediately below.

A very interesting point to notice in this figure is the distribution of the main deformed zone. As already stated, practically all of the movement in the clay below the sand has taken place along a single gliding plane. Near the center of the photograph, where the load is less, it will be noticed that the zone of deformation widens considerably and that five or six beds have been folded or affected by the movement. Just beyond this folded zone in the right-hand section of the photograph, the movement again becomes localized along a single plane for a short distance. Still farther on the movement spreads out, affecting six or seven beds. This tends to show that deformation is not

[7] Owing to the difficulty of photographing the experiment at close range, due to the length of time necessary for exposure and to reflections in the glass tank, the photographs are combined with drawings to bring out the relationship between the clay beds and the sand.

FIG. 7.—Experiment similar to Figure 6, showing variations in character of folded zones. As in Figure 6, faulting below sand occurred before piston thrust. (Illustration is combination photograph and drawing.)

necessarily confined to any one bed or to a single horizon, but may pinch and widen from place to place, and that it is affected by the weight of the overburden.

The details of the larger folds should be noted. Apparently the two clay beds immediately above and below the folds have suffered from a sort of pulling along their lower and upper sides respectively. For instance, the third white bed from the bottom, near the center of the photograph, shows a very irregular upper surface and a regular lower surface. The upper side has partaken of the folds, whereas the lower has not.

Figure 7 shows another experiment similar to the one pictured in Figure 6 and gives an idea of the nature of the variations to be expected. The details of the several experiments of this nature which were performed by the writer, differed, of course, although the essential characteristics in each were the same. Figure 7, a complete view of the entire length of the tank, shows the sand above and below the clay layers. The amount of movement of the upper beds relative to the lower is shown by the piston. The passage of a gliding plane on the left to a folded zone on the right is well shown.

Although the angle of dip of the axial planes of the folds is not the same in all cases, as shown in the two plates, the majority show a dip toward the moving force of 45° or less.

COMPARISON OF STRUCTURES PRODUCED BY SUBAQUEOUS SLUMP AND DIFFERENTIAL MOVEMENT

With the exception of those contorted zones produced directly by the action of some moving object, such as an iceberg, practically all "intraformational corrugated rocks" are produced either by differential movement or by subaqueous slump. It is of interest, therefore, to know the characteristics of either type, if any such exist, in order that the one may be distinguished from the other. It seems that it is not possible to form a set of criteria which can definitely be applied to separate differential movement from slump. As a matter of fact, these two processes are so similar and overlapping that they do not have many distinctive features. What seem to be the best criteria are as follows.

1. Folding produced solely by differential movement is apt to be regular, all folds having the same angle of dip. The bedding, moreover, is often not disrupted.

2. Intraformational folded zones produced by slump are often beveled across the top, due to subsequent erosion, and may be beveled along the bottom, due to slide.

3. Large sections of the bedding may be absent or duplicated in folded zones produced by slump due to actual migration of material.

4. A single or a very thin incompetent bed lying between two highly folded zones suggests two periods of slump with a short period of deposition between. It is believed that such a thin bed could not have existed at the time of the folding of the lower zone.

5. A bowing upward of the beds overlying the folded zone at the crests of the folds suggests slump, but the absence of such bowing does not necessarily imply differential movement, as submarine erosion may level the surface of the folded zone before the deposition of the overlying beds.

DEFORMATION DUE TO DIFFERENTIAL LOADING

Although definite examples of folding or faulting due to differential loading are not known to be common in the field, this phenomenon must necessarily be of considerable geologic importance, especially where deltas are building rapidly seaward and covering the fine-grained sediments of deeper waters.

Figure 8 shows the results of weighting a series of sediments with bags of shot. The layers in the tank are as follows. The lower 1 inch up to the white band is medium fine-grained sand, the alternating white, gray and black bands are bentonite (white) and clay (gray and black). Above the clay and bentonite is more sand similar to the lower layer. The layers were horizontal and not deformed prior to the placing of the bags of shot at one end of the tank. Folding took place immediately after the weighting.

Special attention should be called to the position of the major fold with reference to the weight. This fold is directly in front of the shot. Farther away and equally spaced are two minor folds. It should also be noticed that the dip of the axial planes of the folds is the same, each dipping toward the point of loading.

The trends of the folds, moreover, are parallel with the outer edge of the superimposed load (not evident in the photograph). This is illustrated in Figure 9, in which is shown a delta in process of building. This figure is a drawing of an experiment performed in a tank about 6 feet square. The bottom of the tank was level and a "land area" was built up on one side. The tank was then filled with about 6 inches of water in which about 2 inches of clay were allowed to settle to form an even layer over the part of the tank covered with water. A stream was then caused to flow from the "land area" and a delta was built. As the delta built seaward, small folds formed immediately in front of its outer edge. As many as five folds formed parallel with this edge,

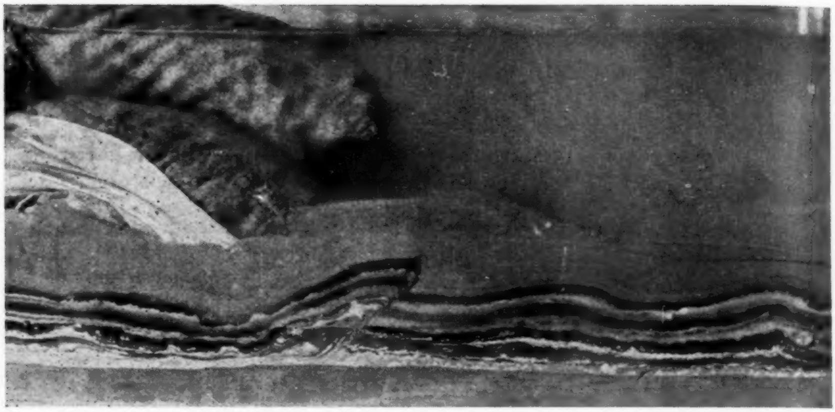

FIG. 8.—Deformation due to differential loading. Basal layer is fine sand; white layers are bentonite; gray layers, gray clays; black layers, black clays. Length of section, about 30 inches.

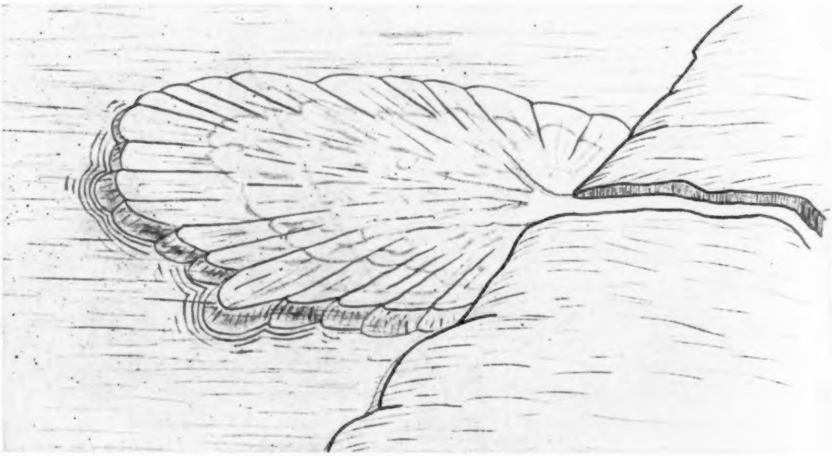

FIG. 9.—Minute folding produced marginal to delta in clays lying beneath and beyond delta. Folding is due to differential loading. Area of delta, about 4 square feet.

the most pronounced being nearest the delta. As the delta built farther into the water, the folds moved along with its advancing edge, and were therefore not covered by the subsequent deposits of the delta, but it is assumed that the clay, which was covered by the sediment of the delta, was considerably disrupted, due to the folding movement. This is later discussed in connection with other experiments.

Uneven loading may produce faulting as well as folding, as shown in Figure 10. In this experiment a 3-inch layer of sand was made on the bottom of a tank, above which were deposited about 3 inches of alternating layers of red and white clay. Over one end of the tank

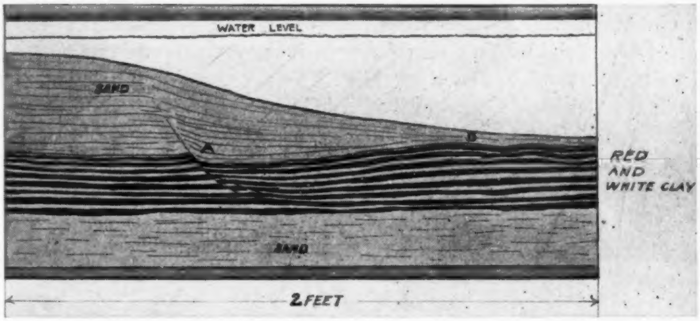

FIG. 10.—Drawing which was made from photograph shows layers of red and white clay resting on sand, with sand above to represent growing delta built over one end. Load produced normal fault shown at *A*.

sand was deposited so as to represent a building delta. Faulting then took place as shown. The fault is normal with downthrow on the side of less weighting, a fact which is at first contrary to expectation, but is perfectly natural when considered in relation to the position of the sand and the point of easiest relief. The fault occurred about midway between maximum loading and no loading, and the mass of sand, together with the underlying clay, moved as though slumping down a slope. Such faulting as this takes place in subaereal landslides and hill creeps and should be rather common on the continental shelf where deposition is building uneven surfaces.

Special notice should be taken of the curvature of the fault plane. Immediately upon passing from the overlying sand into clay beds, the dip of the plane materially lessens, changing from about 55° to about 30°.

It seems evident that if this sand delta were enlarged and built

farther seaward, other normal faults would form, similar to the one pictured. The final result, then, as far as the clay beds are concerned, would be a series of normal faults dipping seaward. This generalization has not been checked in the field, so far as the writer is aware, but it seems obvious that such faulting should be present.

Average measurements taken on the thickness of the clay beds in several experiments, show that those beds underneath the sand body have been compressed about 15 per cent, whereas those just on the edge of the sand have thickened about 10 per cent, making a total difference in the two sections of 25 per cent. These measurements are on beds not immediately adjacent to the fault. This thickening must be due to the effect of folding and to the movement of material to the point of relief.

Differential loading, therefore, produces overturned folds, normal faults, compaction, and thickening. The overturned folds have axial planes which dip toward the load, and have trends parallel to its edge. The normal faults are formed under the load, and are downthrown on the side of lesser loading. In a growing delta, there may be a series of normal faults developed with fault planes dipping away from the point of loading. The strike is parallel with the edge of the load.

EFFECT OF CONTAINED WATER ON COMPETENCY

It is generally known that the competency of loose sands and silts decreases with increased saturation of water, and that partially wet or damp sands have more competency than absolutely dry sands.

In the following experiments an attempt was made to show this change in competency (except of dry sands) by actually deforming a series of sediments. Figures 11, 12, and 13 show the results of thrust movements on medium fine-grained sand interbedded with just enough silt to bring out laminations. In each case, the piston was moved the same distance. In Figure 11, the sediments were deformed while under water. In Figure 12, the water had been drained off 20 minutes, and in Figure 13, 24 hours.

It will be noticed that there is considerable difference in the types of folds formed in the three cases. Those formed under water have a wavy appearance, and as many as four distinct flexures are present. Those folds formed immediately after the water was drained off show sharper and more pronounced angles with just two main flexures, whereas the folding produced in the sediment after the water had been drained off 24 hours shows only one main sharp flexure, closely approximating a fault.

In these illustrations it is interesting to note the distance from the

Fig. 11.—Deformation of sediments while under water by force applied from left. Between sand base and cover are alternating layers of sand and clay. Piston movement was from left to right.

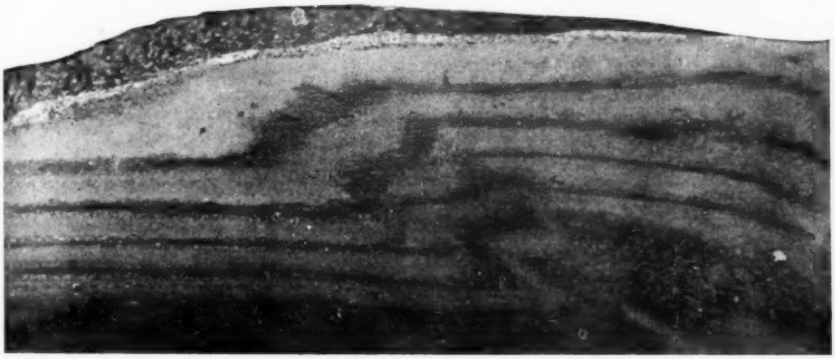

Fig. 12.—Same experiment as Figure 11 except that pressure was applied after water had been drawn off 20 minutes. Piston movement, from right to left.

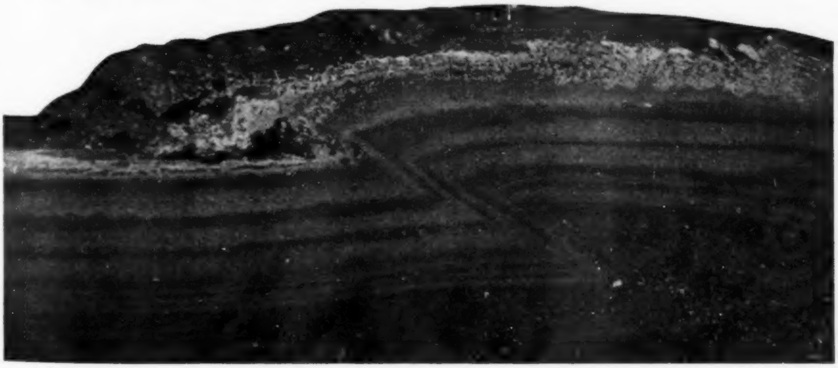

Fig. 13.—Same experiment as shown in Figures 11 and 12 except that pressure was applied after water had been drawn off for 24 hours. Piston movement, from right to left.

piston at which movement took place. In the case of the one deformed under water, the flexures are relatively close to the piston, whereas in those deformed after the water had been drained, the flexures are at a distance.

The foregoing experiment shows how experimental results may be considerably modified by very slight changes in manipulation. The fact that the presence of more or less water in a sand controls the type of folding, indicates that too broad an application of some of the foregoing experiments is not warranted.

AN EXPLANATION OF LANDSCAPE MARBLE

During the course of the experiment with soft sediments, a peculiar condition was unexpectedly produced when a tank containing alternating layers of clay and silt was tipped so as to produce slump. Be fore the angle necessary for slump had been reached, it was noticed that the bedding was being greatly disrupted by small volcano-like eruptions, that the darker-colored silt in the lower dark bed was moving upward through the overlying white clay, and that the darker silt just above this white clay was moving upward to the surface (Fig. 14). The movement was undoubtedly due to the hydrostatic head produced when the tank was tilted. (Note the water level.) The contained water in the sediments at the higher end of the tank moved down dip, causing artesian flow at the volcano-like eruptions. The features thus produced are quite similar to those present in landscape marble. It is suggested, therefore, that landscape marble may be produced when water levels are changed so as to cause movement of water and the formation of a hydrostatic head. Interpreted on a larger scale, this might represent the mechanics of mud lumps on deltas.

EFFECT ON SOFT ROCKS OF FAULTING IN UNDERLYING BEDS

Several experiments were performed in the tank provided with an adjustable bottom so as to simulate faulting of the substratum upon which sediments rest.

One experiment is illustrated in Figure 15. A sequence of sands and clays was subjected to faulting movement by raising the left-hand side of the bottom of the tank. Except where the bottom of the tank moved against the soft sediments, there was no faulting in the sands and clays. All the movement was taken up by folding.

Perhaps the most interesting feature of this experiment is the relationship between the position of the underlying fault and the position of the folding in the overlying beds. It will be noticed that A, the

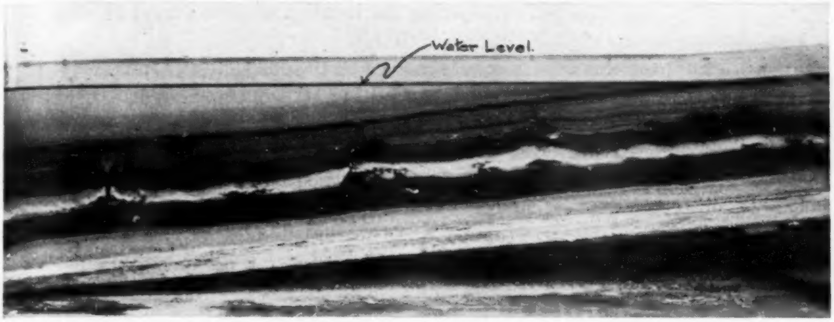

FIG. 14.—Development of landscape marble. Length of photograph, 4 feet.

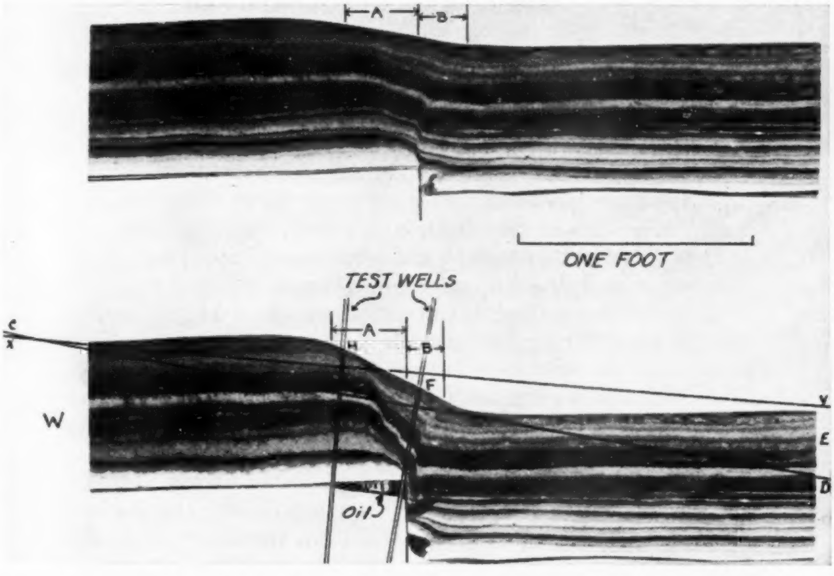

FIG. 15.—Deformation of soft sediments as consequence of faulting in underlying rocks.

distance of movement on the upthrown side, is greater than *B*, the distance of movement on the downthrown side. This might be an important feature when considering the location of tests for oil on dips having a suspected origin similar to this.

Suppose this experiment is magnified to represent a major movement; suppose also that, since faulting, the entire area had been tilted so as to produce a regional dip westward, the line *XY* would then represent the level surface. The highest point structurally on the surface beds would be at *H*. A test well located here might pass west of oil accumulated along the fault.

If the section were further tilted so that line *CD* represented the level surface, then a test well at *F* would penetrate the oil accumulation although located on a surface syncline.

The author realizes that, here, he has applied small laboratory results to major features in the field. Whether or not the drag of the fault in the soft beds would be sufficient to cover any great horizontal distance or not, is difficult to say. A multiplication of the vertical in the above experiment might not result in the same horizontal multiplication.

SOME CHARACTERISTICS IN SOFT ROCKS

It is not known that soft-rock faulting can always be differentiated from hard-rock faulting. In the course of the writer's experiments, one or two characteristics of soft-rock faulting were noted.

Clays and sands which were deformed under water, or while still damp, never showed clean knife-edge breaks. There was always an irregularity of the fault plane and a certain amount of drag. Often this drag was very slight in amount, but it was always present.

It was further noticed that no cavities were produced which might later be filled with cementing material. In some cases, the sediment adjacent to the fault plane became considerably disrupted, forming something like fault-plane filling. This filling, however, usually showed blurred edges and some connection with the side-wall material.

Figure 16 shows a series of faults developed in Dakota sandstone and this illustration brings out the characteristic drag and the fault-plane filling. The fact that the material (light gray) in the fault plane is the same as, and fades into, that composing the side walls, strongly suggests a soft condition of the rock when faulted.

Another point which might be mentioned as showing the condition of the rock at the time of deformation is the non-uniformity of the positions of the faults and the movements along them. Some of the

faults show a displacement in one direction, while others show an opposite movement.

CRITERIA OF SOFT-ROCK DEFORMATION[8]

The following list of criteria for distinguishing structures produced in soft rocks contains some points which are not illustrated in the foregoing pages. Some of these criteria have been pointed out by other authors and some are more or less self-evident. It is thought advisable, however, to assemble as complete a list as possible. Structures produced in soft rocks have the following characteristics.

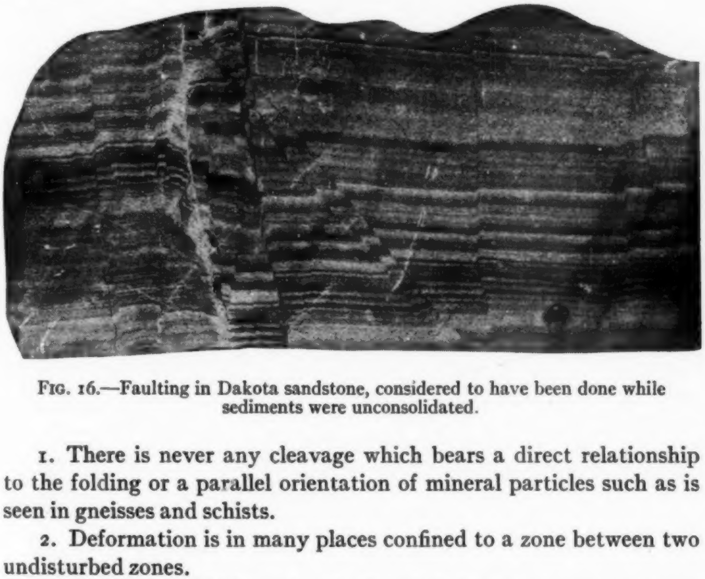

FIG. 16.—Faulting in Dakota sandstone, considered to have been done while sediments were unconsolidated.

1. There is never any cleavage which bears a direct relationship to the folding or a parallel orientation of mineral particles such as is seen in gneisses and schists.

2. Deformation is in many places confined to a zone between two undisturbed zones.

3. Structures (folds) tend to be beveled due to contemporaneous erosion or to sliding, and either top or bottom may be beveled.

4. Structures are, in general, of small size (differential settling on large scale excepted).

5. Structures do not ordinarily show any direct relationship to major diastrophism.

6. Structures and structural arrangement are usually complex, normal and reverse structures being present in the same bed within short distances.

[8] F. H. Lahee, *Field Geology*, 3d ed. (1931), pp. 172–73.
C. K. Leith, *Structural Geology* (revised, 1923), pp. 228–31.

7. There is evidence, in places, of actual migration of sediment. In some cases this migration produces a repetition or omission of beds.

8. Evidence of cavities is entirely lacking. Structures of faulting are usually filled with material similar to the sediment, rather than cement, such as vein quartz.

9. Faults are not sharply defined, but have characteristic drag and blurred edges.

10. Joints, as such, do not exist, except tension joints exemplified by mud cracks.

11. Faults, where present, are usually associated with folded and crumpled beds.

12. It is unlikely that any shells or other rigid animal remains would be deformed. Such deformation suggests hard-rock folding or movement.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 293-299

GEOLOGICAL NOTES

DETERMINATION OF CARBON AND HYDROGEN IN SUBSTANCES OF A BITUMINOUS OR PYRO-BITUMINOUS NATURE OCCURRING IN SHALES[1]

Reliable determinations of the carbon and hydrogen content of bituminous or pyro-bituminous substances associated with shale bodies were required as part of an investigation covering marine oil shale from the Playa del Rey field, California.[2]

An examination of standard analytical methods for these determinations indicated that they would not yield reliable results when applied to shales being investigated. The method here described, which was developed to overcome the shortcomings of the standard methods for determining the carbon and hydrogen content of bituminous or pyro-bituminous substances, is essentially that of Liebig with modifications to suit the particular type of sample analyzed.

Apparatus.—The combustion furnace is of the usual gas type, 34 inches long, with a pyrex combustion tube $\frac{3}{4}$ inch in diameter and 40 inches long. The combustion tube is charged with 4 inches of copper-oxide gauze preceding the combustion boat, 1 inch of copper gauze following the combustion boat, about 16 inches of coarse copper-oxide wire, 1 inch of copper-oxide gauze, a 4-inch cartridge of lead chromate, and 1 inch of copper gauze. The oxygen is purified before entering the combustion tube by bubbling through an 8-inch bead-packed tower of sulphuric-chromic acid and then through a tower packed with calcium chloride and ascarite. The water and carbon dioxide formed from the combustion are collected in improved Nesbitt absorption tubes charged with calcium chloride and ascarite, respectively. The combustion boat is of alundum, 3 inches long. All connections are made with pure gum tubing.

Procedure.—The procedure is typical of the Liebig method, with the exception that care must be exercised in preventing the excessive heating of the lead chromate.

Discussion.—The samples analyzed contain varying proportions of

[1] Published by permission of Desaix B. Myers, chief geologist, and R. E. Haylett, director of manufacturing, Union Oil Company of California.

[2] H. W. Hoots, A. L. Blount, and P. H. Jones, "Marine Oil Shale, the Source of Oil in Playa del Rey Field, California," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, No. 2 (February, 1935), pp. 172-205.

sulphur, nitrogen, and halogens that would seriously affect the results if run according to the method of Liebig. For this reason, copper gauze and lead chromate are used. The copper gauze reduces any oxides of nitrogen that may be formed, allowing free nitrogen to pass through the tube. The sulphur and halogens are removed by the lead chromate to form lead sulphate and the corresponding chromium halide.

Results from the combustion of benzoic acid, naphthalene, aniline, and other substances of known composition, indicate that variations not exceeding 0.3 per cent from the true value may be expected from this method.

Any water of crystallization and water of composition present in a sample of shale analyzed for carbon and hydrogen by the combustion method described in the previous paragraphs will be computed as hydrogen and will introduce a serious error in the hydrogen determination.

Efforts have been made, therefore, to develop a procedure which will permit correction for water of crystallization and water of composition, and encouraging results have been obtained in preliminary tests using the procedure here outlined.

A weighed sample of shale is introduced into a small retort about 20 mm. in diameter and 150 mm. long, which is clamped in a vertical position. A gas delivery tube extends to the bottom of this retort, and provision is made for withdrawing gas near its top, and for introducing a thermocouple for measuring the temperature. Nitrogen is passed through the retort containing the shale sample, and then through a small glass absorption tube containing a high boiling refined lubricating oil which is kept at about 212° F. with a water bath. The gas then passes through a small glass "equilibrium" coil suspended in a water bath held at about 100° F., and then into a calcium-chloride tube, which is also suspended in a water bath held at about 130° F. After the apparatus has been swept free of air with a stream of nitrogen, which is kept running during the entire test, the retort is heated with a gas flame.

The water of crystallization and composition is thus driven out of the shale sample, and is carried through the apparatus by the stream of nitrogen until it reaches the calcium chloride, where it is absorbed. The lubricating oil dissolves, and retains, most of the hydrocarbon gases liberated, but it is kept at a sufficiently high temperature to prevent the retention of water. Any condensible material passing out of the lubricating oil is brought to equilibrium with the gas stream at about 100° F., in the equilibrium coil, which is provided

with a bulb sufficiently large to prevent the removal of any material from it in the liquid phase. Since the calcium-chloride tube is held at a higher temperature than the equilibrium coil, no liquid phase can appear at this point, and the gain in weight of the calcium chloride is due almost entirely to the retention of water of crystallization and composition driven out of the shale sample. The final temperature in the retort is about the same as that reached in the ordinary combustion analysis (1200° F.). The hydrogen in the water recovered is then deducted from the hydrogen obtained from the regular combustion analysis.

It is possible that the calcium chloride used in this correcting method retains materials other than water, and also it is possible that some of the oxygen containing organic matter decomposes at high temperatures to produce water. However, it seems probable that most of the gain in weight of the calcium chloride comes from water of crystallization and composition, as it has been observed that, during the first part of a run when the temperature is below 400° F., such large volumes of water are evolved that it condenses on the glass tubing used in the apparatus.

The correcting method described has not been tested sufficiently to establish its limitations, and subsequent work may show that it can not be relied upon, but the preliminary work indicates that it may have considerable value in improving the accuracy of the combustion analyses of shale samples.

H. W. Hoots
A. L. Blount
P. H. Jones

Los Angeles, California
August 7, 1934

OCCURRENCE OF *BACULITES OVATUS* ZONE OF UPPER ALBERTA SHALES IN SOUTHEASTERN BRITISH COLUMBIA

The rocks known as the Alberta shale series of the Upper Cretaceous in western Canada were given this name by G. S. Hume in 1929.[1] The Alberta shale embraces the Colorado (Benton) and Montana series, but it is differentiable into these elements only on a faunal basis. Two formations or monothems[2] are recognized in the Alberta.

[1] G. S. Hume, "The Highwood-Jumping Pond Anticline with Notes on Turner Valley, New Black Diamond, and Priddis Valley Structures, Alberta," *Geol. Survey Canada Summ. Rept. 1929*, Pt. B (1930).

[2] K. E. Caster, "The Stratigraphy and Paleontology of Northwestern Pennsylvania, Part I: Stratigraphy," *Bull. Amer. Paleont.*, Vol. 21, No. 71 (1934), p. 17.

The lower of these was termed Blackstone shale by Malloch in 1911.[3] The Blackstone is entirely of Colorado age and is probably contemporaneous or at least homotaxial with the Turonian of Europe. The upper monothem is known by Malloch's name, Wapiabi shale. Within the Wapiabi occurs a gradation in fauna and deposition from the Colorado to the Montana series. The *Cardium* sandstone initiated the deposition of the Wapiabi monothem. The name Cardium was more broadly applied by Hector in 1858.[4] In 1914 Cairnes[5] delimited the name to supplant the preoccupied name Big Horn sandstone which Malloch had used for the basal Wapiabi member.

Through the work of Hume,[6] Warren and Rutherford,[7] and Webb and Hertlein,[8] the Alberta series has been rather thoroughly zoned both lithologically and faunally. Warren and Rutherford recognized essentially six fossil zones in the Alberta series. These were reduced to four by the comprehensive studies of Webb and Hertlein. All of these workers recognize a barren zone at the base of the Blackstone shale. A zone of *Inoceramus labiatus* succeeds the barren zone. Webb and Hertlein included in their *I. labiatus* zone the *Prionotropis* zone of Warren and Rutherford. Next is the *Scaphites ventricosus* zone, which includes the *Cardium perpauculum* sandstone and the lower part of the Wapiabi shale. The fossils of the *S. ventricosus* zone are the highest Colorado fauna in the Alberta series. Overlying the *S. ventricosus* zone in the upper Wapiabi shale is a zone of fossils characterized by representatives of the *Baculites ovatus* species group[9] and *Desmoscaphites bassleri*. This fauna is viewed as Montanan in age. The previous workers have likened the *B. ovatus* fauna of the Alberta series to that of the Pierre of the Dakotas and of the apparently equivalent Telegraph Creek shale and Eagle sandstone of the Montana series in southern Montana.

Webb and Hertlein differentiate several lithologic zones in the Al-

[3] G. S. Malloch, "Bighorn Coal Basin, Alberta," *Geol. Survey Canada Mem. 9-E* (1911).

[4] James Hector, *Report of the Palliser Expedition, 1859.*

[5] D. D. Cairnes, "Moose Mountain District, Southern Alberta," *Geol. Survey Canada Mem. 61* (1914).

[6] See footnote 1.

[7] P. S. Warren and R. L. Rutherford, "Fossil Zones in the Colorado Shale of Alberta," *Amer. Jour. Sci.* (5), Vol. 16, No. 92 (1928), pp. 128–36.

[8] J. B. Webb and L. G. Hertlein, "Zones in the Alberta Shale in the Foothills of Southwestern Alberta," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18, No. 11 (1934), pp. 1387–1416.

[9] The cephalopods referred to *B. ovatus* in the Alberta shale must be reviewed in the light of the work of M. K. Elias on the cephalopods of the Pierre formation of Wallace County, Kansas, and adjacent area (*Bull. Univ. Kansas*, Vol. 34, No. 5, 1933).

berta monothems. Those of the Wapiabi are, briefly, from bottom to top: (1) the *Cardium* sandstone zone or member at the bottom of the Wapiabi; the Wapiabi proper is divided into (2) approximately 450 feet of platy shale over which there is a zone (3) of approximately 450 feet of concretionary shale; above this last shale is (4) a transition zone approximately 125 feet thick which is of marine origin in the lower part and of fresh-water origin in the upper. A massive sandstone of fresh-water origin usually overlies the transition zone. This last belongs to the Belly River formation. The *Baculites ovatus* fauna ranges through the concretionary shale zone and into the upper part of the platy shale zone.

The main purpose of this note is to call attention to an interesting occurrence of the *Baculites ovatus* fauna in southeastern British Columbia at a point well within the Rocky Mountain area. This development is separated from the nearest occurrence of the Alberta shale by several miles. The separating interval is chiefly occupied by rocks of pre-Cambrian and Paleozoic age. In the November, 1934, paper by Webb and Hertlein it is mentioned that *Baculites ovatus* had not been discovered by them as far south as the Crowsnest area (although it had previously been reported from that district by McLearn).[10]

During field work on the western edge of Glacier National Park and along the western side of the Waterton Lakes Preserve, discovery was made of an occurrence of the *Baculites ovatus* zone. The position of the discovery is about 27 miles south of Crowsnest Pass and approximately 28 miles south of Lundbreck, Alberta. It is about 18 miles north of the International Boundary. The exposure is in the bed and along the north bank of Cate or Graveyard Creek, a small stream which has its source along the Alberta and British Columbia boundary in the Clark Range of the Rocky Mountains. The stream flows toward the southwest into the North Fork of Flathead River. If the land subdivisions of Alberta are extended into British Columbia the position of the Cretaceous outcrop is located in the southwestern part of T. 4 N., R. 8 W., 5th Meridian, western part of the Clark Range.

It is well known that the Rocky Mountains in this area are composed principally of rocks belonging to the Belt terrane of Cryptozoic age. It is also well known that the eastern edge of this Belt sequence has been overthrust for several miles upon the Cretaceous rocks of the Alberta plains. The Cretaceous occurrence on Cate Creek

[10] F. H. McLearn, "Stratigraphic Paleontology (Blairmore District, Alberta)," *Canada Nat. Mus. Bull.* (1929), pp. 80–107.

is approximately 1.5 miles east of the western edge of the mountains, therefore well within the general area of pre-Cambrian strata.

The stratigraphic and structural geology of this area and more particularly of the whole Flathead area in the United States and Canada, west of the mountains, will be the subject of a comprehensive paper. It will perhaps suffice for the present to indicate that these Cretaceous beds which carry the *Baculites ovatus* fauna lie in a structural condition of overthrusting beneath black and shaly limestones belonging to the Altyn formation of the Belt terrane. The condition agrees very closely with the fault relation so fully described by Bailey Willis along the Lewis overthrust on the eastern edge of Glacier National Park. The Altyn limestone is greatly sheared, thus forming a minor thrust zone. The shear planes and minor faults dip essentially toward the west and southwest. The shear zone is overlain by relatively unbroken Appekunny argillites. So sharp is the upward delimitation of the minor shear zone that from a distance it resembles an erosional unconformity.

The Cretaceous exposures occur for approximately 0.75 mile along the north wall of the box-canyon valley of Cate Creek. The lowest exposures consist of black, rather fissile shale; the highest consist of rather coarse micaceous sandstone, olive-green in color. There are several exposures of these strata, isolated between rock slides and glacial debris. The actual contact with the overlying Altyn limestone is concealed, but its position can be closely approximated. The black shales are only relatively disturbed and contain a moderately well preserved and rather large fauna. The large shells of *Inoceramus lundbreckensis* and *Baculites ovatus* are the most common fossils. The complete fauna at present known from this member is:

Inoceramus lundbreckensis McLearn
Ostrea congesta Conrad
Anomia sp.
Baculites ovatus Say
Desmoscaphites bassleri Reeside
Numerous fish scales.

The overlying sandstones are fossiliferous, but as yet the fauna is known only from loose blocks in the stream. This fauna is chiefly comprised of fresh-water pelecypods belonging to the Naides stock.

The lithologic character and sequence of the formations belonging to the Upper Cretaceous on Cate Creek suggest the correlation of the black shales with the concretionary shale zone of Webb and Hertlein in the upper part of the *Baculites ovatus* zone. The overlying sandstone unit may belong in their transition zone, or even in the Belly River

group. The fauna of the black shales establishes definitely the presence of the basal Montana series in the southeastern part of British Columbia, thereby furnishing an intermediate tie-point in the correlation between central and northern Alberta and the United States. Eventually, no doubt, the entire fauna of the *Baculites ovatus* zone will be discovered in southern Alberta. From the Calgary Geological Map Number 204-A of the Canadian Geological Survey, it is seen that the British Columbia locality lies near or along the southward extension of the Alberta shale outcrop of the Crowsnest area, beneath the Belt series, and it shows in a rough manner the extent of overthrusting of the Belt series upon the younger rocks of the plains region. Evidently the position of the shore line of the Cretaceous sea fluctuated widely, but during Upper Alberta time it was presumably several miles west of the present outcrop of these beds and therefore well within the area of the present Rocky Mountains.

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KENNETH E. CASTER

CORNELL UNIVERSITY
ITHACA, NEW YORK
January 5, 1935

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 300-305

REVIEWS AND NEW PUBLICATIONS

Petroleum Investigation. Hearings before a subcommittee of the Committee on Interstate and Foreign Commerce, House of Representatives, Seventy-Third Congress (Recess) on House Resolution 441, September 17–22, 1934. Part 2, containing: "A Résumé of Geology and Occurrence of Petroleum in the United States," by the UNITED STATES GEOLOGICAL SURVEY; "A Report on Petroleum Development and Production," by H. C. MILLER and BEN E. LINDSLY; and "A Report on Effect of Technologic Factors on Supply of and Demand for Petroleum Products," by A. J. KRAEMER. Pp. 869–1390; 132 figs. Size, 6×9 inches. Supt. Pub. Documents, Gov't. Printing Office, Washington, D. C. Price, paper, $1.75.

This is an information report on the general conditions in the United States oil industry, written in three parts as indicated by the titles. It is printed for the use of the Committee on Interstate and Foreign Commerce.

The publication contains so much that is of interest and value to every geologist, engineer, oil man, or student of the problems of the industry, that it deserves reprinting and a wide distribution. It would make a valuable library reference in all schools teaching geology, especially with reference to the economics of oil production and its engineering problems relative to oil and gas conservation.

It is the most complete condensed publication on the oil industry that ranges from its history before the Christian era to the present.

Every investor in oil stocks, or other forms of investment in the industry, would profit by carefully reading the report for its wealth of general information in the several oil-producing areas and its outline of the legal problems.

MARVIN LEE

WICHITA, KANSAS
December, 1934

Scientific Results of the Snellius Expedition in the Eastern Part of the Netherlands East Indies, 1929–1930. Vol. V. *Geological Results.* Part 2. "Geology of Coral Reefs." By PH. H. KUENEN. Kemink en Zoon N. V.—Utrecht (1933). 125 pp., 106 figs., XI pls. 12.5×9 inches. Cloth, $11.50.

This is one of the most interesting treatises on coral reefs which it has been the reviewer's good fortune to read. The figures and plates are most illuminating and splendidly executed. They are not only clearly printed, but give the reader a clear conception of the mode of occurrence, distribution, structure, and relation to the sea floor of recent reefs. Fellow-geologists, and especially those working in west Texas, who have described many so-called reefs from the middle and upper Permian, will find much food for thought in the structure and composition of reefs as described by Kuenen. The investigations were conducted in the eastern part of the Dutch East Indies, where the reefs are of great extent and are growing under exceptional conditions which present every type of environment, such as numerous volcanic,

non-volcanic, and coral islands, stable and unstable areas and specialized climate. A better area could not have been chosen.

Chapter I, "Introduction," consists of an outline of the work done and a brief discussion of the previous work done in the area by other writers.

Chapter II is a description of the reefs investigated and is confined wholly to observations made in the field. Discussion of various theories and problems is reserved for a later chapter. This chapter is illustrated by many figures.

Chapter III is concerned with observations on coral growth and is divided into three parts: Part 1. Reef Contacts; Part 2. The Formations of Micro-Atolls; Part 3. Conditions Adverse to Coral Growth (volcanic action, silt, elevation, et cetera). From the viewpoint of the petroleum geologist, parts 1 and 3 should be greatly enlarged because of the possible bearing upon oil reservoirs.

Chapter IV deals with positive and negative movements of the sea-level. This chapter is also divided into three parts. Part 1 is on recent negative movements. Part 2 is on the destruction of raised reefs. Part 3 takes up the influence of larger changes of sea-level on reef development. Part 1 is of particular interest because of the almost worldwide occurrence of certain negative movements. Part 2 discusses the effect of atmospheric weathering on raised reefs, while Part 3 discusses the possible effect of the glacial period upon ancient reefs.

Chapter V, which is divided into five parts, explains the character of the reef flats. Part 1 discusses the effect of the absence of *Lithothamnium* in the East Indies. Part 2 discusses the character of the surface of reef flats. Part 3 discusses the character, origin, and position of shingle ramparts, mangrove swamps, and sand clays. Part 4 discusses "negro-heads," those interesting large, round blocks of coral reef, which occur on some reef flats. Part 5 is on the peculiar cementation of coral sand.

Chapter VI is on the formation of atolls. This chapter sets forth the author's conceptions of how and why reefs grow where they do. It also explains the cause and effect of the formation of barrier reefs, fringing reefs, and atolls. The theories of Darwin, Murray, and Gardiner are set forth with a pro and con discussion. Measurements of the submarine reef slopes are presented with some interesting anomalies. The effect of the structure of the surrounding sea bottom upon the formation of reefs and their relative position is gone into with considerable detail. A very interesting set of facts is presented on the depth of lagoons and how it fits into the various theories of reef formation. The absence of dolomitization of reefs, except where exposed or in elevated masses above mean sea-level, should be of much interest to the Mid-Continent geologist. Finally, a discussion of the theory of glacial control is very complete and the facts deduced are of a negative nature. The facts brought out are of such a nature that it seems doubtful if glacial control has had any effect on coral growth or the position of the reefs.

Chapter VII is a summary of all the facts brought out in the preceding chapters.

Chapter VIII is a very complete bibliography of practically all important works on coral reefs.

In concluding, it may be said that the format is a beautiful piece of work. The binding is novel and the printing is very clear; there are, however, a number of typographical errors. The one difficulty with the publication is its

unusually large size, which makes it hard to hold while reading. However, this slight inconvenience should not be a serious drawback to this very excellent piece of work.

ROBERT ROTH

WICHITA FALLS, TEXAS
December 17, 1934

Report of the Committee on the Measurement of Geologic Time. ALFRED C. LANE, chairman. National Research Council Meeting of the Division of Geology and Geography, Washington, D. C., April 28, 1934. Mimeographed, 86 pp.

This report presents in a detailed but concise manner the progress that has been made during the past year on the problem of the measurement of geologic time by radioactive methods. The report is headed by a short summary by A. C. Lane, chairman of the committee, after which follow 20 somewhat detailed reports by workers in the field. The main topics considered are quantitative age determinations and reliability and development of methods. About a dozen new age determinations are presented, which correspond fairly closely with previous measurements. Some of the rocks analyzed and the ages reported are Hot Spring terrace deposits, Yellowstone National Park, 14,000 years; a Miocene dike, 28 million years; early Eocene of Colorado, 64–80 million years; Triassic dike at New Haven, 170 million years; Permian, 196 million years; Devonian (Caledonian revolution), 278–88 million years; Silurian (Taconic revolution), 377 million years; Lower Cambrian or Keweenawan, 580 million years; and granitic rocks at Great Bear Lake, 1,277 million years.

PARKER D. TRASK

WASHINGTON, D. C.
January, 1935

National Research Council, Division of Geology and Geography, Annual Report for 1933–1934 (mimeographed), Washington, D. C. [The stock of complete annual reports is now practically exhausted and the supply of committee separates is limited.]

The annual reports of the Division of Geology and Geography, National Research Council, are perhaps not so widely read by petroleum geologists as are the separate reports of the Committee on Sedimentation, yet these yearly reports of the entire Division contain much that bears directly on many problems of petroleum geology. The current volume includes the minutes of the annual meeting of April 28, 1934; a summary of the year's activities by the retiring chairman of the Division, W. H. Twenhofel; and the reports, presented in twenty-two appendixes, of the different committees and associated organizations.

The committee reports are, for the most part, summaries of progress and of plans being laid in some of the more active fields of geology. However, several of the summaries also include current bibliographies and even the results of original research. Many petroleum geologists will be particularly interested in the reports of the following committees.

Micropaleontology.—In addition to a summary of recent activities, five supplementary reports cover special fields of investigation. One of these, on film copies of rare publications, will be of interest to many besides micropaleontologists.

Accessory minerals of crystalline rocks.—Those engaged in heavy-mineral studies will find suggestive material in the report of this committee, particularly in the abstracts of current literature on accessory minerals.

Paleobotany.—Current paleobotanic work in America is reviewed, with especial emphasis on ecologic interpretations, and an annotated bibliography of paleobotany in North America is given for the year.

Studies in petroleum geology.—Brief statements of the individual research work and activities of committee members.

Stratigraphy.—Further progress is reported in the organization of this committee, the major objective of which is stated to be "the synthesis of our present knowledge of the post-Proterozoic stratigraphy of North America."

Tectonics.—Recent developments in the field of structural studies are summarized, including, among many other outstanding activities, a discussion of plans for a tectonic map of the United States and an appropriate mention of the publication of Bucher's book on crustal deformation.

Conservation of scientific results of drilling.—Brief reports from designated national depositories of the cores and cuttings that have been received and studied.

Isostasy.—Among other recent developments, new determinations of gravity have been made by the Coast and Geodetic Survey at many points in Wyoming, Montana, Texas, Florida, and Cuba.

Aerial photographs.—This committee recommends that those "interested in examining aerial photographs or in securing copies of them get in touch with Mr. J. H. Wheat, Chief of the Map Information Office of the Federal Board of Surveys and Maps," United States Geological Survey, Washington, D. C.

Most of the other committee reports are of equal interest. To mention only a few of many items: the statement of prospects for continued publication of the Annotated Bibliography of Economic Geology; the preliminary notice of papers to be published in the Biennial Report of the Committee on Sedimentation; the abstracts of recent investigations of Mississippi Valley ore deposits, particularly those bearing on the origin of the Boone chert; new determinations of lead-uranium ratios from rocks of very different ages in many regions; and the projected drawing-up of specifications for an ideal state geological survey. Many readers of the Association *Bulletin* will likewise be interested in the reports of the Division representatives on (1) the Advisory Committee of the American Association for Water Well Drillers and (2) the Committee on Classification of Coal, American Society for Testing Materials. In fact, these annual summaries of recent activities in many special fields serve admirably to remind us that, in one way or another, petroleum geology impinges more or less directly on virtually every field of geological inquiry.

WILLIAM W. RUBEY

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D. C.
January 11, 1934

RECENT PUBLICATIONS

GENERAL

Um das geologische Weltbild (On the Geological Picture of the World), by Erich Haarmann. 119 pp., 23 figs., 1 table. Ferdinand Enke, Stuttgart-W. (1935). Lex. 8°. RM. 5.80.

"Paleozoic Plankton of North America," by Rudolf Ruedemann. *Geol. Soc. America Mem. 2* (November, 1934). 141 pp. incl. index, 6 figs., 26 pls. Outside dimensions, 6.75×10.25 inches. Cloth.

Tulsa Geological Society Digest (1934). Edited by G. S. Dillé. Abstracts of 18 articles presented before the Society during 1934. 63 pp., 8 illus. 6×9 inches. Paper. Available at $0.50 per copy from Sam H. Woods, Secy., Box 1348, Tulsa, Oklahoma.

"Age of the Midway Group," by Gayle Scott. *Bull. Geol. Soc. America*, Vol. 45 (December 31, 1934), pp. 1111–58; 3 pls., 1 fig.

"Tectonica y acumulaciones petroliferos" (Tectonics and Petroleum Accumulations), by J. A. Broggi. *Bol. Soc. Geol. Peru* (Lima, 1934, Tomo 6, Fasc. 1. 49 pp., 8 figs. A contribution to the 16th International Geological Congress at Washington, D. C., July, 1933.

GEOPHYSICS

"Sul procedimento di carotaggio elettrico" (Electrical Coring), by A. Belluigi. *Bol. Com. Geodesia e Geofisica Consiglio Nazionale Ricerche*, Ser.2, Vol. 4, Nos. 1–2 (July, 1934). 8 pp.

"L'exploration électrique des sondages" (Electrical Coring), by C. and M. Schlumberger and H. G. Doll. *Revue Pétrolifère* (Paris), No. 609 (December 15, 1934), pp. 1525–30; 9 figs. First installment of this article.

GERMANY

"Zur Erdölhöffigkeit Nordostdeutschlands" (*Petroleum Possibilities in Northeast Germany*), by S. von Bubnoff. *Kali, Verwandte Salze und Erdöl* (Berlin), Vol. 28, No. 24 (December 15, 1934), pp. 305–08.

ILLINOIS

Papers on Improved Methods of Exploring for and Recovering Petroleum in Illinois. 12 papers and discussions on subjects including air repressuring, water flooding, and acid treatment, presented at the 2d annual Petroleum Conference, at Robinson, Illinois, June 1, 1934. Sponsored by the Illinois-Indiana Petroleum Association and the Illinois State Geological Survey, Urbana. 74 pp., illus.

KANSAS

"Development of the Oil and Gas Resources of Kansas in 1931 and 1932," by Edward A. Koester. *State Geol. Survey Kansas Min. Resources Cir. 3* (1934), 76 pp. 6×9 inches. Paper. Mailing charge from Lawrence, Kansas, $0.20.

"Cephalopods of the Pierre Formation of Wallace County, Kansas," by Maxim K. Elias. *State Geol. Survey Kansas Contrib. Paleon. Kansas No. 3.* 75 pp. Mailing charge, $0.05.

OKLAHOMA

"Geology and Economic Significance of the Oklahoma City Field," by Basil B. Zavoico. *World Petroleum* (New York, January, 1935), pp. 11–25; 3 colored maps, 5 photos, 8 tables.

PERU

"Memoria y bibliografia" (History and Bibliography), by J. A. Broggi. *Bol. Soc. Geol. Peru* (Lima, 1934), Tomo 6, Fasc. 2, 124 pp. Bibliographic abstracts on geology, botany, and zoölogy of Peru from 1929 to 1933 inclusive.

STUDY OF STRUCTURE OF SUWA BASIN, NEAR KYOTO, JAPAN, BY TORSION BALANCE

CORRECTION

In the article, "Study of Structure of Suwa Basin, Near Kyoto, Japan, by Torsion Balance," by M. Matsuyama, Y. Fujita, and H. Higashinaka, published in the January *Bulletin*, the following corrections should be made.

Page 58, at the head of the article, the name of the first author should read: *M. Matuyama;* and that of the third author, *H. Higasinaka.*

Page 60, line 3 from the bottom, Bureau of Geodesy should be *Geodetic Commission.*

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 306-308

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Gustav Frischknecht, Point-a-Pierre, Trinidad, B. W. I.
H. G. Kugler, E. Lehner, C. W. Halse
William Sibley Pike, Jr., Houston, Tex.
Julian D. Sears, John B. Reeside, Jr., Joseph T. Singewald
Manuel Rivero, Maracaibo, Venezuela, S. A.
E. A. L. Gevaerts, H. Hemmings, J. Dufour
Stuart Sherar, Tulsa, Okla.
James E. LaRue, Dave P. Carlton, L. P. Teas

FOR ASSOCIATE MEMBERSHIP

Helen Pier Bird, McCamey, Tex.
J. Ben Carsey, M. B. Arick, John Emery Adams
Robert Leeroy Breedlove, Austin, Tex.
F. L. Whitney, F. M. Bullard, E. H. Sellards
Thomas Noble Roberts, Oklahoma City, Okla.
Charles E. Decker, V. E. Monnett, E. E. Lindeblad

FOR TRANSFER TO ACTIVE MEMBERSHIP

Harry X. Bay, Urbana, Ill.
Urban B. Hughes, A. C. Trowbridge, A. C. Tester
Lee Cherry Smith, Dallas, Tex.
James A. Waters, F. H. Lahee, F. E. Heath
George C. Williams, Los Angeles, Calif.
Emil Kluth, N. A. Rousselot, Paul P. Goudkoff

TWENTIETH ANNUAL MEETING, WICHITA, MARCH 21-23, 1935

The Kansas Geological Society, in arranging for the twentieth annual meeting of the Association, extends to every member a cordial welcome to Wichita, Kansas, March 21-23, 1935. A program of technical value and general interest is being provided and entertainment for all members and guests is assured. Members are cordially invited to bring their wives.

The Allis Hotel is headquarters and all technical sessions will be held there, including meetings of the divisions of paleontology and geophysics.

Titles of manuscripts and abstracts should be sent immediately to Walter

A. Ver Wiebe, chairman of the program committee, University of Wichita, Wichita, Kansas. Paleontology papers should be sent before March 1 to Gayle Scott, Texas Christian University, Fort Worth, Texas, and geophysics papers to B. B. Weatherby, Box 2040, Tulsa, Oklahoma.

No cards will be required for admission to technical sessions. However, tickets must be presented by everyone at all entertainment features. No convention registration fee will be required.

A one-day trip to a salt mine at Lyons, by way of oil fields, principally in the Burrton area, is being arranged for Saturday or Sunday, March 23 or 24.

Another field trip, Sunday and Monday, March 24 and 25, will afford opportunity to study the Permian and Pennsylvanian rocks of eastern Kansas under the leadership of Raymond C. Moore, State geologist. The cost of all trips will be based on actual expense, those attending paying pro rata.

A banquet will be held at the Allis Hotel and at the Lassen Hotel, Friday night, March 22, followed by dancing at both places. Special entertainment will be provided.

The golf tournament will be held at the Wichita Country Club, Friday, March 22. Courtesy cards will be provided upon request at time of registration.

A feature of the entertainment program will be a musicale by Dean Thurlow Lieurance of Wichita University, nationally known composer.

The local committee has secured agreement from the hotels that there will be no advance above regular rates. Reservations should be made immediately by each member directly to the hotel of his choice. Confirmation of reservation should be requested. If difficulties are encountered, communicate with E. P. Philbrick, Box 1882, Wichita, Kansas.

The railroads are granting reduced rates based on fare and one third for the round trip, with stop-overs and 30-day return limit. Printed notices about hotel rates together with railroad convention certificates are being mailed to members.

Additional information will be supplied by local Wichita committees; address E. C. Moncrief, chairman general committee, 358 North Broadway, Wichita, Kansas.

The Association research committee, Donald C. Barton, chairman, will hold its annual dinner and round-table discussion on Wednesday evening, March 20, preceding the official opening of the convention. The subject is "Cases of Migration or Non-Migration of Oil." All members are welcome.

In addition to the preliminary program listed on page 132 of the January *Bulletin*, the following subjects of papers have been offered for the program.

R. C. Moore, "Classification of Late Paleozoic Rocks of the Mid-Continent Region"
Coleman Hunter, "Gas Production of the Devonian Shale"
C. W. Tomlinson and M. P. White, "Structure of the Arbuckle and Ouachita Mountains"
W. I. Ingham, "The Wellington Oil Field, Colorado"
David White, "Metamorphism of the Organic Sediments and the Derived Oils"
A. A. Baker, "Geologic Structure of Southeastern Utah"
P. D. Trask, "The Problem of Petroleum Generation"
O. C. Postley, "Natural Gas Developments and Possibilities East of Main Oil and Gas Fields of Appalachian Region"
W. B. Lang, "Permian Formations of Pecos Valley of Texas and New Mexico"
T. A. Hendricks, "Some Variations in Fixed Carbon in Coals of Arkansas-Oklahoma Coal Field"

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

William B. Heroy, *chairman*, New York, N. Y.
M. G. Cheney, *secretary*, Coleman, Texas
Frank R. Clark, Tulsa, Oklahoma
Edwin B. Hopkins, Dallas, Texas
L. C. Snider, New York, N. Y.

GENERAL BUSINESS COMMITTEE

Sam M. Aronson (1936)
Arthur A. Baker (1936
R. A. Birk (1936)
M. G. Cheney (1935)
Frank R. Clark (1935)
H. E. Crum (1935)
E. F. Davis (1936)
Joseph A. Dawson (1935)
Frank W. DeWolf (1935)
C. E. Dobbin (1935)
James Terry Duce (1935)
H. B. Fuqua (1935)
M. W. Grimm (1935)
S. A. Grogan (1935)
William B. Heroy (1936)
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John F. Hosterman (1935)
Edgar Kraus (1935)
Roland W. Laughlin (1935)
O. C. Lester, Jr. (1935)
Theodore A. Link (1935)
R. T. Lyons (1935)
Roy G. Mead (1935)
A. F. Morris (1935)
L. Murray Neumann (1936)
Philip E. Nolan (1935)
Clarence F. Osborne (1935)
Gayle Scott (1935)
A. L. Selig (1935)
L. C. Snider (1935)
J. D. Thompson, Jr. (1936)
J. M. Vetter (1936)
Paul Weaver (1935)
E. A. Wendlandt (1935)
Maynard P. White (1935)
E. A. Wyman (1935)

RESEARCH COMMITTEE

Donald C. Barton (1936), *chairman*, Humble Oil and Refining Company, Houston, Texas
A. I. Levorsen (1935), *vice-chairman*, Tide Water Oil Company, Houston, Texas

C. E. Dobbin (1935)
Alex W. McCoy (1935)
C. V. Millikan (1935)
L. C. Snider (1935)
L. C. Uren (1935)
Harold W. Hoots (1936)
R. S. Knappen (1936)
W. C. Spooner (1936)
Parker D. Trask (1936)
M. G. Cheney (1937)
Robert H. Dott (1937)
K. C. Heald (1937)
F. H. Lahee (1937)
H. A. Ley (1937)
R. C. Moore (1937)
F. B. Plummer (1937)

REPRESENTATIVE ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. S. Knappen (1937)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

Ira H. Cram, *chairman*, Pure Oil Company, Tulsa, Oklahoma

John G. Bartram
M. G. Cheney
Alexander Deussen
B. F. Hake
G. D. Hanna
M. C. Israelsky
A. I. Levorsen
C. L. Moody
R. C. Moore
Ed. W. Owen
J. R. Reeves
Allen C. Tester
W. A. Thomas

TRUSTEES OF REVOLVING PUBLICATION FUND

Frank R. Clark (1935)
Charles H. Row (1936)
Ralph D. Reed (1937)

TRUSTEES OF RESEARCH FUND

Alex W. McCoy (1935)
Robert H. Dott (1936)

FINANCE COMMITTEE

W. E. Wrather (1935)
Joseph E. Pogue (1936)
E. DeGolyer (1937)

COMMITTEE ON APPLICATIONS OF GEOLOGY

F. H. Lahee, *chairman*, Box 2880, Dallas, Texas

William H. Atkinson
Arthur E. Brainerd
H. A. Buehler
Hal P. Bybee
Frank R. Clark
Herschel H. Cooper
Carey Croneis
H. B. Hill
Earl P. Hindes
Marvin Lee
S. E. Slipper
E. K. Soper
J. M. Vetter

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO. 2 (FEBRUARY, 1935), PP. 309-310

Memorial

JOSEF THEODOR ERB

On October 24, 1934, Dr. Josef Theodor Erb died at the Hague at the age of 60 years. His sudden and unexpected passing was a great loss to his country, to science, to his many close and admiring friends and associates, and innumerable scientific and business acquaintances. Since 1900 he had been uninterruptedly in the service of the Royal Dutch-Shell Group; he was a member of the board of directors when he died.

Dr. Erb was born on February 25, 1874, at Volkach (Bavaria), of Swiss nationality. He was educated in Switzerland, where in 1896 he obtained the doctor's degree in geology at the University of Zurich, where he remained as a much appreciated assistant to the famous Alpine geologist, Professor Albert Heim. He entered the services of the Royal Dutch Petroleum Company in 1900, beginning with 3 years of geological field work in Sumatra. Serious illness (malaria) interrupted his activities in 1903, and necessitated return to Europe. He used the period of convalescence by following a course of economic geology at Charlottenburg. In March, 1905, he made a new trip to the East Indies, this time to Java. In September he returned to Europe. From 1906 to 1908 he worked in Roumania and while there acted as secretary of the geological division of the 1906 petroleum congress at Bucharest. From 1908 to 1912 he travelled widely for the rapidly spreading interests of his company, and worked in California, Roumania, Egypt, Sarawak (Borneo), Gallicia, Oklahoma, Russia, and Mexico. During this time he repeatedly came to headquarters at the Hague and in London for conferences. His activities were not confined to geology, but included problems of organization, land deals, and many other business matters. In 1912 he was made chief geologist and head of the central geological department of the group. During these activities, which lasted until 1921, he continued to travel at frequent intervals, notably to America and Russia. In 1921 he was made one of the managing directors and at the same time became a Netherlands subject. In 1929 he was elected a member of the board of directors of the Royal Dutch-Shell. He continued to make personal visits to many of the foreign offices, notably in Mexico, Venezuela, the East Indies, Sarawak, the United States, and Roumania.

It is greatly to be regretted that a practical scientist of such ability and exceptional experience as Dr. Erb, had practically no opportunity to leave publications accessible to the public. He grew up with an entirely new science, petroleum geology, and was largely instrumental in establishing it, by the very personal guidance he gave to all the geologists of his company, which was a pioneer in scientific exploration. He never had time, however, for publications; also the policy of his directors was adverse to publicity. The files of the company, naturally, contain a treasure of numerous reports from his hand, and as chief geologist he has digested and commented on innumerable reports of geologists and managers throughout the world. Those that knew

these reports and Dr. Erb's comments appreciate the enormous scope of his knowledge and his exceptionally acute mind, which never permitted a mistake to pass unnoticed. Nevertheless he always was a friendly and understanding adviser to all his associates, never lost his original simplicity and amiability, was always helpful and true. He knew how to maintain this attitude under sometimes difficult circumstances, which required great tact and diplomacy, as insiders realize. He was universally liked by compatriots as well as by foreigners. He made a point of knowing the language of all countries and peoples with whom he had important relations; apart from his native German and the acquired Dutch, he conversed in English, French, Malay, Roumanian, Spanish, and Russian.

W. A. J. M. van Waterschoot van der Gracht

Maastricht, Holland
January, 1935

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 19, NO 2 (FEBRUARY, 1935), PP. 311-316

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

RAY G. GREENE has recently been employed by the Schlumberger Well Surveying Corporation, and is stationed at 303 Haberfelde Building, Bakersfield, California.

J. D. WHEELER, geologist with the Marathon Oil Company, has been transferred from Henderson to Iraan, Texas.

OLIVER P. NICOLA, JR., formerly of 2012 West Cherokee Street, Enid, Oklahoma, is now at 1613 Cedar Street, Saginaw, Michigan.

WARREN B. WEEKS, geologist, Phillips Petroleum Company, has been transferred from Amarillo, Texas, to Shreveport, Louisiana.

ALEXANDER DEUSSEN, consulting geologist of Houston, Texas, spoke at the quarter-centennial celebration of the University of Texas on natural resources, at Austin, on "Thirty-five Years of Progress in the Knowledge of the Geology of Texas."

DALE R. SNOW, who has been vice-president in charge of geology and land for Barnsdall Oil Company, has been appointed vice-president in charge of production in place of W. K. WHITEFORD, resigned. The two departments have been consolidated under the new management.

At a recent meeting of the Kansas Geological Society, the following officers were elected: president, HOWARD S. BRYANT, Skelly Oil Company; vice-president, JAMES I. DANIELS, Continental Oil Company; secretary-treasurer, WARD VICKERY, Vernon Oil and Gas Company.

PAUL J. FLY, formerly resident geologist at Hattiesburg, Mississippi, for the Humble Oil and Refining Company, is now working for the same company in southeast Louisiana and south Mississippi and may be addressed at the Rowland Apartments, Baton Rouge, Louisiana.

The following men were recently elected Fellows of the Geological Society of America: ROBERT H. DOTT, Tulsa, Oklahoma; GEORGE M. FOWLER, Joplin, Missouri; MAYNARD P. WHITE, Ardmore, Oklahoma; W. B. WILSON, Tulsa, Oklahoma.

MERLE C. ISRAELSKY, geologist, United Gas Public Service System, Houston, Texas, addressed the December meeting of the Shreveport Geological Society on "A Faunal Zonation of the Claiborne of East Texas and Louisiana."

J. WHITNEY LEWIS has returned to Dallas, Texas, after a geological study of the Dominian Republic. His address is Stoneleigh Court, Dallas.

J. A. McCutchin, exploitation engineer, Shell Petroleum Corporation, has been transferred to Pampa, Texas, as district exploitation engineer, to assume the duties of S. F. Bolby, who left for The Hague, Holland.

A. H. Richards, formerly with the Ramsey Petroleum Corporation, and Lon B. Turk, formerly with the Independent Oil and Gas Company, have formed a partnership for the practice of consulting geology and will have offices at 633 First National Bank Building, Oklahoma City.

Lenora May Williams, of the geological staff, Amerada Petroleum Corporation, Tulsa, was married on December 15, to James R. Hunt, of the Geophysical Research Corporation, Tulsa.

The 144th annual meeting of the American Institute of Mining and Metallurgical Engineers, 29 West 39th Street, New York City, will be held in New York, February 18–21. The Hotel Commodore, 42d Street and Lexington Avenue, is the hotel headquarters.

Robert McNeely, of Wichita, Kansas, is credited with finding and leasing the Wakeeney structure in western Kansas.

R. V. Hollingsworth, recently studying for his Doctor's degree at the University of Chicago, is now paleontologist with the Shell Petroleum Corporation at Tulsa, Oklahoma.

The Geological Society of New Mexico, at Carlsbad, has elected the following officers for the new year: president, Delmar R. Guinn; vice-president, Ralph Koenig; secretary, Neil H. Wills; treasurer, George Kroenlein.

The Schlumberger Well Surveying Corporation of Houston, Texas, announces that Alexander Deussen, consulting geologist, has been elected a director of the corporation.

At a meeting of the Tulsa Geological Society, Monday, January 21, the following papers were presented: "Asphalt and Its Relation to Oil Deposits," by E. G. Woodruff; "Discussion of Asphaltites and Asphaltic Pyrobitumens and Their Formation," by R. L. Ginter.

Vaughn W. Russom, formerly at Jacksonville, Texas, with the Sinclair Prairie Oil Company, has been transferred to the Tulsa, Oklahoma, district, and is stationed temporarily at McAlester.

Harry X. Bay has been appointed to a position in the subsurface division of the Illinois State Geological Survey, and may be addressed at Urbana.

Otto E. Brown has changed his address from Ada, to 522 East Wichita Street, McAlester, Oklahoma.

Harry E. Crum, geologist with the Columbian Carbon Company, has changed his address from Charleston, West Virginia, to New York City.

William L. Russell, formerly of 430 Temple Street, New Haven, Connecticut, is now with the Tidewater Oil Company, at Tulsa, Oklahoma.

The National Research Council has been given funds for grants-in-aid for the year 1935. Applications for grants from this fund must be in the

hands of the secretary of the Committee on Grants-in-Aid, 2101 Constitution Avenue, Washington, D.C., on or before April 1, 1935. Additional information and blank forms for filing applications will be furnished upon request. Action on these applications will be taken about the middle of May. At meetings in November and December, 1934, the Committee on Grants-in-Aid made the following awards in the fields of geology and geography: KENNETH E. CASTER, instructor in geology, Cornell University, "The Stratigraphy and Paleontology of the Pocono Formation of Pennsylvania and Adjoining Territory"; MAURICE EWING, instructor in physics, and ALBERT P. CRARY, assistant in physics, Lehigh University, "A Geophysical Investigation"; FRANK F. GROUT, professor of geology, University of Minnesota, "The Mechanics of Igneous Action"; ELMER H. JOHNSON, industrial geographer, Bureau of Business Research, University of Texas, "Physical and Economic Characteristics of the Natural Regions of the Gulf Southwest"; GEORGE W. RUST, postgraduate student in geology, University of Chicago, "Studies of a Newly Discovered Center of Ancient Volcanic Activity in Southeastern Missouri"; J. RUSSELL WHITAKER, assistant professor of geography, University of Wisconsin, "Regional Geography of Southern Ontario."

The Appalachian Geological Society, Charleston, West Virginia, has elected the following officers for the year 1935: president, O. FISCHER; vice-president, J. E. BILLINGSLEY; secretary-treasurer, ROBERT C. LAFFERTY.

Announcement has been made of the selection of FRED E. WOOD, of the Standard Oil Company (Indiana), Chicago, Illinois, as national chairman of the American Petroleum Institute's central committee on drilling and production practice for 1935. Other national officers include T. V. MOORE, Humble Oil and Refining Company, Houston, Texas, vice-chairman, and CARL A. YOUNG, secretary of the Institute's Division of Production, Dallas, Texas, secretary. The following have been appointed national chairmen of topical committees: drilling practice, W. T. DOHERTY, Humble Oil and Refining Company, Houston; production practice, D. R. KNOWLTON, Phillips Petroleum Company, Bartlesville, Oklahoma; allocation of production, FRED E. WOOD; metallurgy and corrosion of oil field equipment, B. B. WESCOTT, Gulf Research and Development Corporation, Pittsburgh, Pennsylvania; development and production research, G. V. D. MARX, Standard Oil Company of California, San Francisco, California; well spacing, R. D. WYCKOFF, Gulf Research and Development Corporation, Pittsburgh; production records, J. FRENCH ROBINSON, Peoples Natural Gas Company, Pittsburgh; and production nomenclature, J. F. DODGE, University of Southern California, Los Angeles.

The American Petroleum Institute, fifth mid-year meeting, will be held at the Mayo Hotel, Tulsa, Oklahoma, May 14, 15, and 16. The sixteenth annual meeting of the Institute will be held at the Biltmore Hotel, Los Angeles, California, November 11, 12, 13 and 14, 1935.

At a meeting of the Council of the Society of Economic Geologists at Rochester, New York, December 27, 1934, the following officers were declared elected: president for 1936, DONNEL F. HEWETT; first vice-president for 1936, JOHN WELLINGTON FINCH; councillors for 1935–36, GEORGE M. FOWLER, DONALD C. BARTON, ERNEST F. BURCHARD. L. C. GRATON is serv-

ing as acting secretary during the absence of the secretary, from February 1 to July 1, 1935, on a trip to Australia. W. E. WRATHER is president of the Society for 1934-35.

J. S. HUDNALL, member of the firm of Hudnall and Pirtle, consulting geologists of Tyler, Texas, gave a paper before the regular meeting of the Shreveport Geological Society on February 1, entitled "Compaction of Reservoir Rocks and Its Relation to the Production of Oil."

G. A. WARING is the author of "Core Drilling for Coal in the Moose Creek Area, Alaska," published as *Bulletin 857-E* of the United States Geological Survey.

GEORGE R. BOYLE presented a paper before the regular monthly meeting of the San Antonio Geological Society, February 4, entitled "The Samfordyce Field, Hidalgo County."

At the annual meeting of the Fort Worth Geological Society, held at the Worth Hotel, January 7, the new officers for the year 1935 were elected as follows: president, S. H. CASTEEL, Box 2077, Petroleum Building; vice-president, ALAN BRUYERE, Box 1160, The Texas Company; secretary-treasurer, C. D. CORDRY, Gulf Production Company.

EDWIN A. TAEGEL, formerly with the Mexican Gulf Oil Company, Tampico, is now with the Shell Petroleum Corporation, and is stationed at Rio Grande City, Texas.

CHARLES R. HOYLE, geologist with the Phillips Petroleum Company, has been transferred from Oklahoma City to Amarillo, Texas. His address is 2038 Hughes Street.

RICHARD HUGHES, geologist with Burke-Greis Oil Company, Tulsa, presented a paper before the Tulsa Geological Society, February 4, entitled "A Geologic Travelogue of Morocco and Algeria."

M. MILSTEIN, mining engineer and geophysicist, formerly with the Royal Dutch Company, in Mexico, is engaged in geophysical prospecting in Australia, and may be addressed at Milstein and Company, Geophysical Surveys, Ltd., 361 Royal Parade Parkville, N. 2, Melbourne, Victoria.

The council of the American Association for the Advancement of Science has elected, among other officers, the following for the year 1935: president, KARL T. COMPTON, Massachusetts Institute of Technology; general secretary, OTIS W. CALDWELL, Teachers College, Columbia University; vice-president and chairman of Section E (Geology and Geography), WALTER E. MCCOURT, Washington University.

WILLIAM G. BLANCHARD, president of the Oil Development Company of Florida, has announced arrangements to drill a 6,000 well (unless oil or gas in commercial quantities, or crystalline or metamorphic material, is encountered at less depth) in Lake County, Florida.

ROBERT H. DOTT, consulting geologist, Tulsa, Oklahoma, is the author of a series of three articles on "Kansas' Future Crude Oil Reserve Status,"

in the *Oil Weekly*. The first article appeared in the issue of January 21 and the second in the issue of February 4.

GROVER C. POTTER, formerly of San Antonio, Texas, is chief of the geological and land departments of the D. and D. Oil Company at Mission, Texas.

L. E. TROUT, geologist of San Antonio, has moved his office from the Bedell Building to 1011 South Texas Bank Building. He is associated in consulting work with JOHN R. STERRET, geophysical operator.

CHARLES R. FETTKE, professor of geology, Carnegie Institute of Technology, is the author of a paper "Gas and Oil Possibilities of Oriskany Sandstone, Northwest Pennsylvania," in the January 31 issue of the *Oil and Gas Journal*, pp. 113–14.

EUGENE B. GERMANY, president of the C. and G. Oil Company, Dallas, is president of the Independent Petroleum Association of Texas.

H. F. MOSES, recently in Ankara, Turkey, is geologist for the Carter Oil Company, with headquarters at Denver, Colo.

STANLEY C. HEROLD, geologist and engineer, Glendale, California, writes on "Today's Oil Technology—and Tomorrow's," in *Petroleum World* (Los Angeles) of January, 1935.

GEORGE M. HALL, professor of geology, University of Tennessee, Knoxville, is president of the Tennessee Academy of Science.

The officers of the Geological Society of America for 1935 are: president, NEVIN M. FENNEMAN; past-president, W. H. COLLINS; vice-presidents, EDSON S. BASTIN, DONNEL F. HEWETT, JOHN B. REESIDE, JR., AUSTIN F. ROGERS; secretary, CHARLES P. BERKEY; treasurer, EDWARD B. MATHEWS; councillors, FRANK F. GROUT, W. O. HOTCHKISS, JOSEPH STANLEY-BROWN, F. W. DEWOLF, DONALD H. MCLAUGHLIN, ADOLF KNOPF, WALTER H. BUCHER, RUSSELL S. KNAPPEN, E. L. BRUCE.

SAMUEL M. MAYFIELD, Linfield College, McMinnville, Oregon, is State Geologist of Oregon.

GRADY KIRBY, formerly district geologist with the Sinclair-Prairie Oil Company, has opened a consulting office at 707 Jefferson Street, Beeville, Tex.

F. W. PENNY, consulting geologist, Ploesti, Roumania, has an article, "Roumania Expects Greater Production as Result of Recent Exploration Work," in the *Oil Weekly* of January 28. It is illustrated by a sketch map of the Ploesti area.

ELMER L. LUCAS, of Phillips University at Enid, Oklahoma, presented a paper on "Petrographic Character of the Pennsylvanian Sands in the Ardmore Basin," before the Oklahoma City Geological Society, January 4.

JOHN DOERING, geologist with John R. Black, Tower Petroleum Building,

Dallas, spoke before the Houston Geological Society, January 17, on the "Post-Fleming Formations of the Gulf Coastal Plain."

R. D. PARKER, civil engineer, with the Texas Railroad Commission for 25 years, E. V. FORAN, petroleum engineer, formerly with the United States Bureau of Mines, and W. F. KNODE, petroleum engineer, recently with the Texas Railroad Commission, have organized as a firm of consulting petroleum engineers at Austin, Texon, and Corpus Christi, Texas.

GEORGE R. PINKLEY has returned from work for the Standard Oil Company at Venezuela, at Caripito, and has resumed his consulting work in South Texas.

CHANGE OF ADDRESS

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